AD-776 207

EVALUATION OF THE ADVANCED (SWINDELL)
HELIUM-OXYGEN DIVING HELMET

Stephen D. Reimers, et al

Navy Experimental Diving Unit
Washington, D. C.
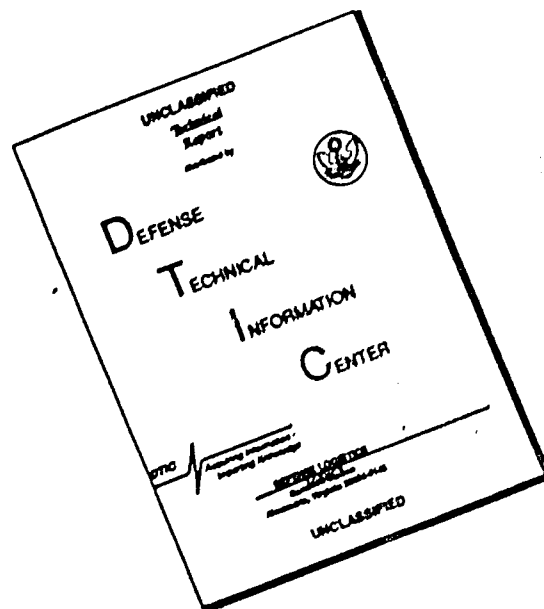
14 August 1973

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NAVY EXPERIMENTAL DIVING UNIT

WASHINGTON NAVY YARD

WASHINGTON, D.C. 20390

NAVXDIVINGU REPORT 10-73
EVALUATION OF THE
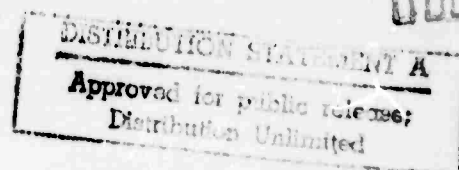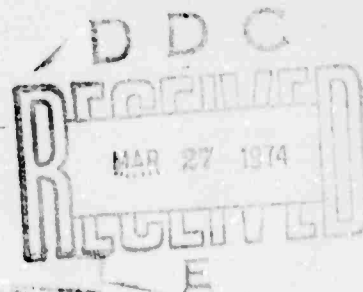ADVANCED (SWINDELL)
HELIUM-OXYGEN DIVING HELMET
S.D. Reimers
H.C. Langworthy
J. Hesket
14 August 1973

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ABSTRACT

The Advanced (formerly Swindell) Model 3610 Mixed Gas
Diving System manufactured and distributed by the Diver's Exchange,
Inc. of Harvey, LA was subjected to evaluation testing at the
Navy Experimental Diving Unit. The Model 3610 System consists
primarily of a Model 3000 Mixed Gas Helmet used with a neckseal
and a Model 3700 Back Pack Scrubber. The system was tested for
sound levels and ventilation efficiency using specially built test
manikins. It was tested for diver comfort in a series of 20
manned dives. Since many of the testing methods used were new,
a discussion of the procedures used as well as the results obtained
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to be into the damage risk levels under many of the conditions tested,
but not so far as to preclude use of the system provided that
appropriate precautions are taken. The ventilation efficiency of
the system was found to be generally adequate for diving in the
depth range of 0 to 300 fsw provided the gas supply pressure is
maintained at sufficient levels. The system was regarded by the
divers as generally more comfortable than the standard USN He-O_2
diving outfit. Nonetheless diver complaints of helmet and jock
strap discomfort became common at work rates approximating moderate
work.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
DIVING EQUIPMENT						
HELMETS						
HYPERBARBIC NOISE						
HEARING						
DIVER'S HEARING LOSS						

I. INTRODUCTION

In 1970, the Navy Experimental Diving Unit began a program to develop a combination air and helium-oxygen diving helmet that would be an improvement over the traditional MK V air and helium-oxygen helmets. Part of this program was a series of evaluations of commercially available helmets.

This report details the tests performed using the Advanced (formerly Swindell) Model 3610 Mixed Gas Diving System. The Model 3610 system includes the Advanced Model 3000 Mixed Gas Helmet with neckseal and the Advanced Model 3700 Mixed Gas Back Pack Scrubber.

Since many of the evaluation techniques used were new, a discussion of the techniques used is also included.

Appreciation is expressed to the Naval Medical Research Institute for their cooperation in the conduct of this evaluation.

II. EQUIPMENT TESTED

The "Advanced" He-O$_2$ Diving Helmet was initially developed and manufactured by Mr. George Swindell. He sold it as a central part of a general line of He-O$_2$ diving equipment under the company name of Advanced Diving Equipment & Manufacturing, Inc. Today the helmet is commonly referred to by both the names "Swindell" and "Advanced". "Advanced" is the name used in this report.

Mr. Swindell sold his helmet business in 1971 to Beckman Instruments, Inc. Beckman in turn sold it in early 1973 to Diver's Exchange, Inc. (DIVEX) of 2245 Breaux Ave., Harvey, LA. 70028. DIVEX is the company that manufactures and markets the "Advanced" helmet line at this time.

Figure 1 shows an exploded view of the Model 3000 Mixed Gas Helmet, neckseal and jock strap. Figure 2 shows an exploded view of the Model 3700 Back Pack Scrubber. Figure 3 shows the assembled helmet, back pack scrubber, and emergency gas bottles sometimes used with the system. Figure 4 shows rear and right side views of the helmet, neckseal and back pack as they would typically be worn by a diver. Figure 5 shows a front view of the helmet only on a diver.

The helmet is constructed primarily of a moulded fiberglass shell with nickel and chrome plated brass fittings. The air control and exhaust assemblies are attached to the brass base piece and not to the fiberglass shell. The viewports are made of fracture-resistant polycarbonate. The exhaust valve assembly is very similar in construction and performance to that in the U.S. Navy Mark V Air Helmet. Muffling of the noise of the in-coming air is effected by the use of a sintered metal silencer.

The air control valve requires approximately 4 turns to go from the fully closed position to the fully open position. The exhaust valve requires approximately 3 turns. All Working seals are effected by the use of "O" rings.

The exhaust port from the helmet to the cannister suction hose is simply an open hole located in the side of the helmet above and slightly to the rear of the helmet exhaust valve (See Figure 3). The exhaust port employs a standard SCUBA 1-way valve to prevent water entry in the event the suction hose is cut. The inlet port into the helmet from the back pack return hose is another open hole located above the helmet gas control valve (See Figure 4). It has a standard SCUBA 1-way valve to prevent opening a second helmet exhaust point in the event the return hose is cut. It also has a shroud (Figure 1, item 3729) to direct the returning gas forward toward the faceplate.

Both back pack hose connections can be capped in the event the helmet is to be used in an open circuit mode. When used in this manner the helmet functions in a manner identical to that of the Advanced Model 2000 Air Helmet except that the entering air is directed down from the top of the faceplate instead of across from the right side. See Reference 1.

Back pack scrubber construction is primarily welded stainless steel. The driving agent in the back pack is a venturi type aspirator jet similar to that in the USN Mark V He-O_2 Diving Helmet. The canister takes a 9 lb. Baralyme[TM] charge and

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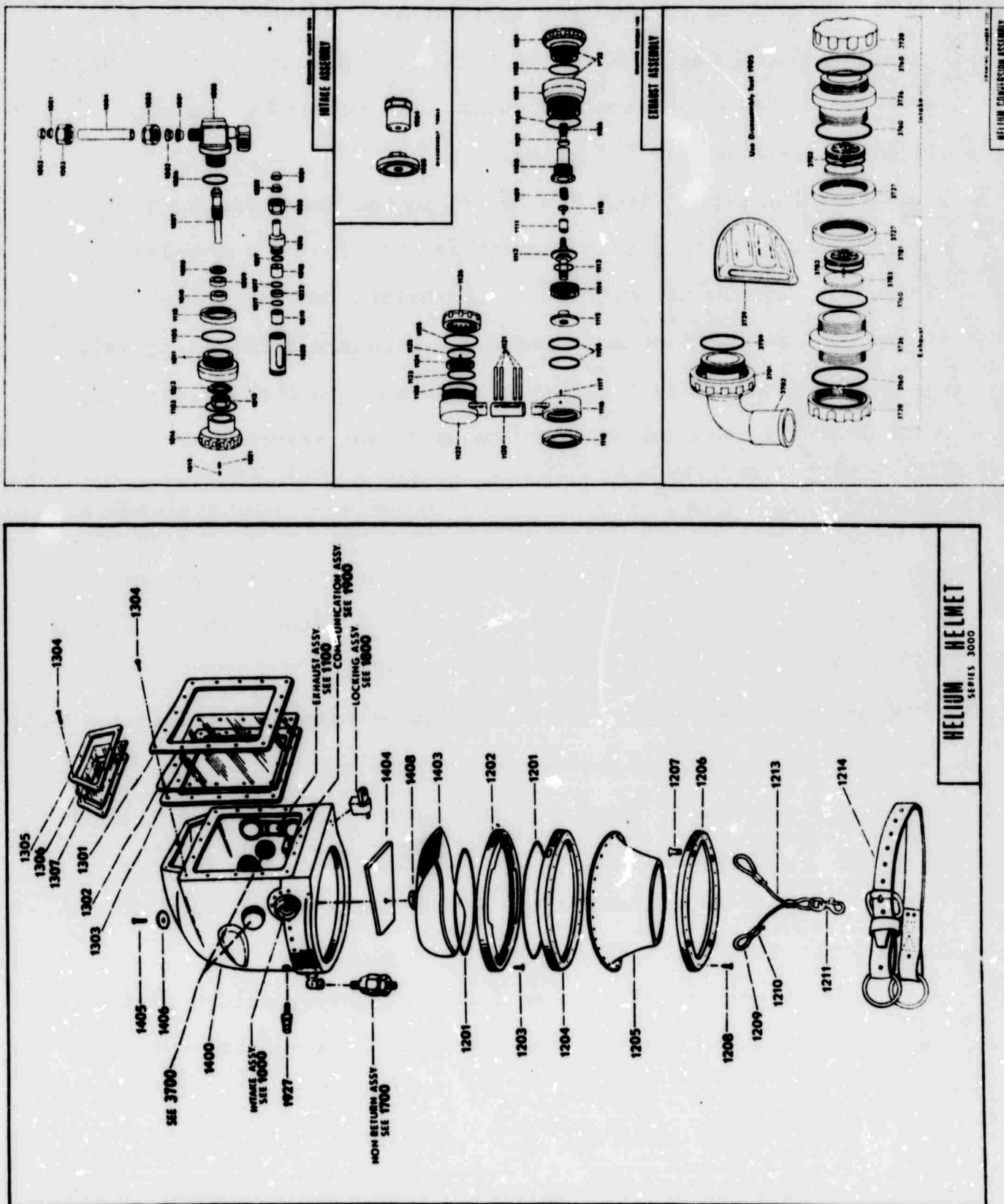
Figure 1   Exploded View, Advanced Mixed Gas Helmet, Model 3000

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HELIUM-OXYGEN SCRUBBER PACK ASSEMBLY
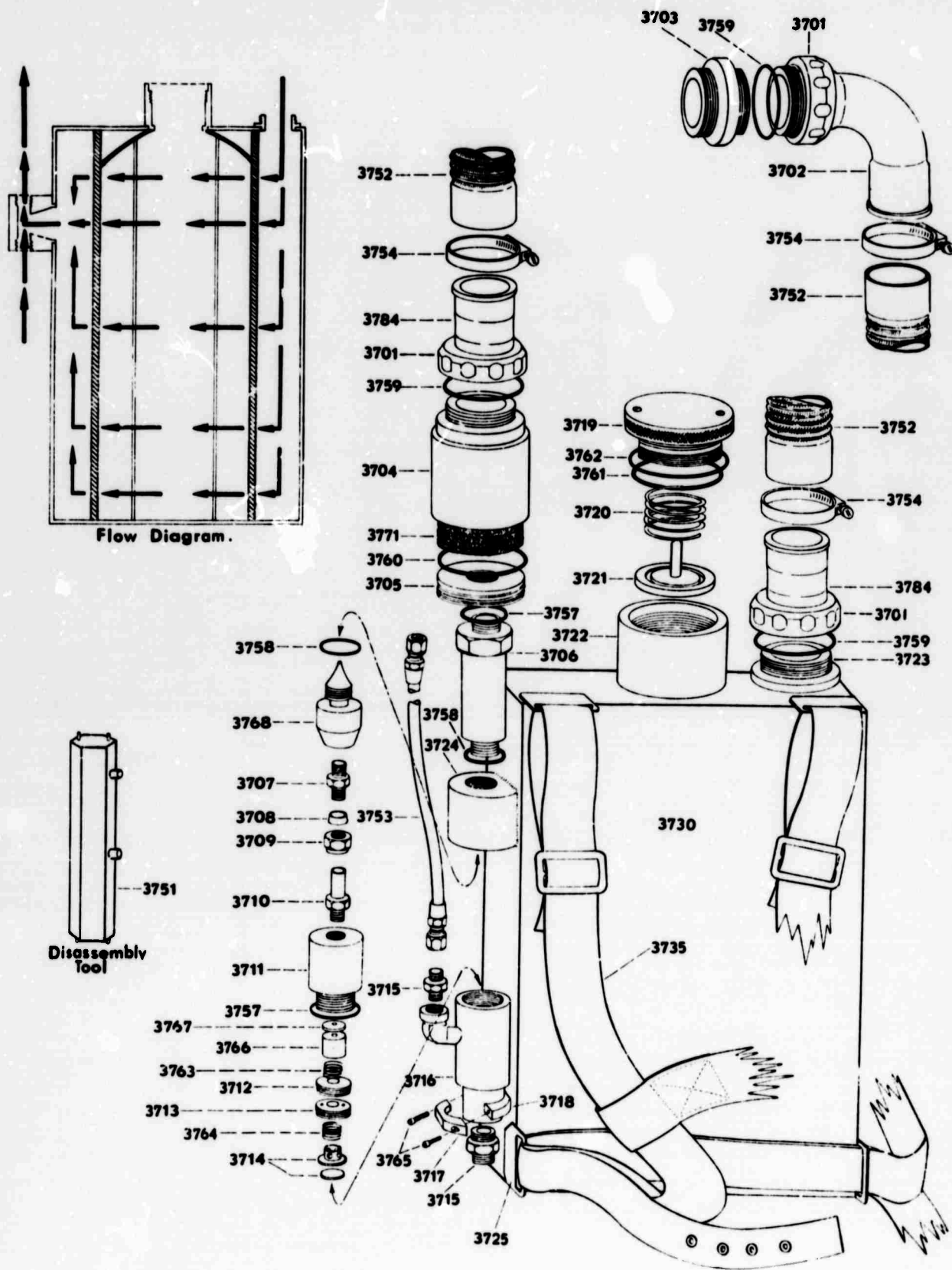
Figure 2   Exploded View, Advanced, Model 3700, Mixed Gas Back Pack Scrubber
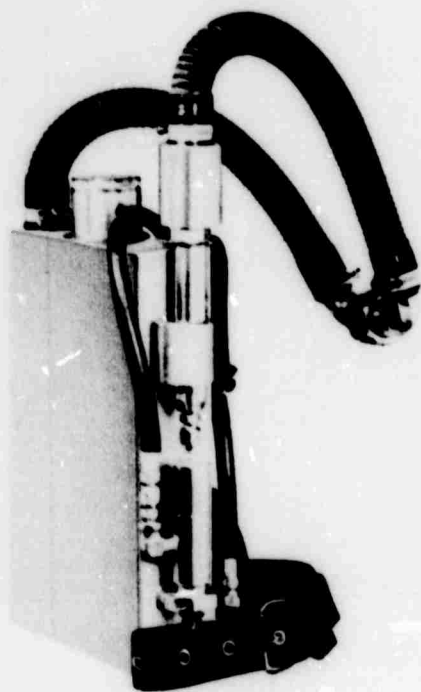
Model 3000
Mixed Gas Helmet
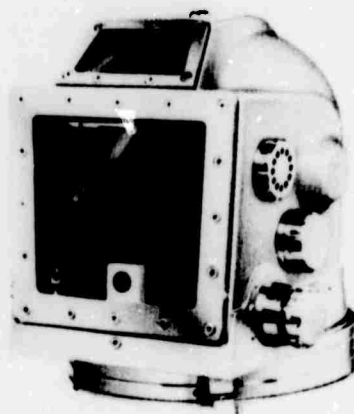
Model 3700
Back Pack Scrubber
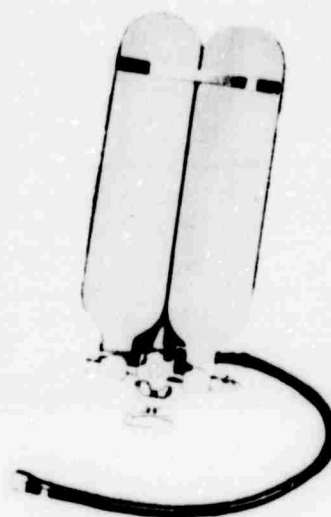
Model 5000

Emergency Breathing System
20 scf capacity at 2200 psig.

Figure 3

Advanced Model 3000 Mixed Gas Helmet,
Model 3700 Back Pack Scrubber and
Model 5000 Emergency Breathing System

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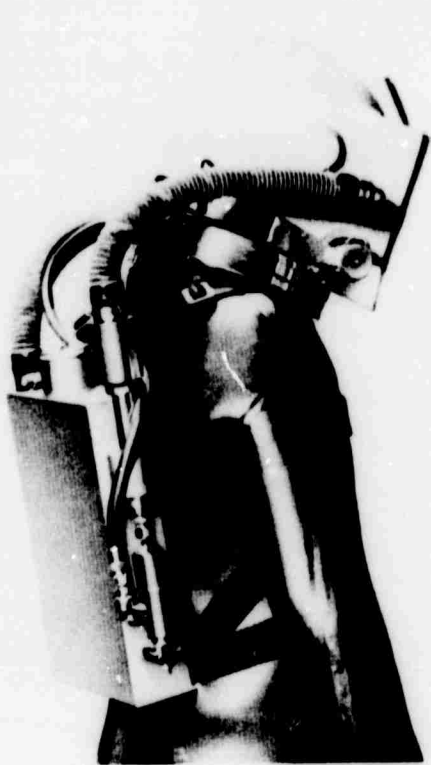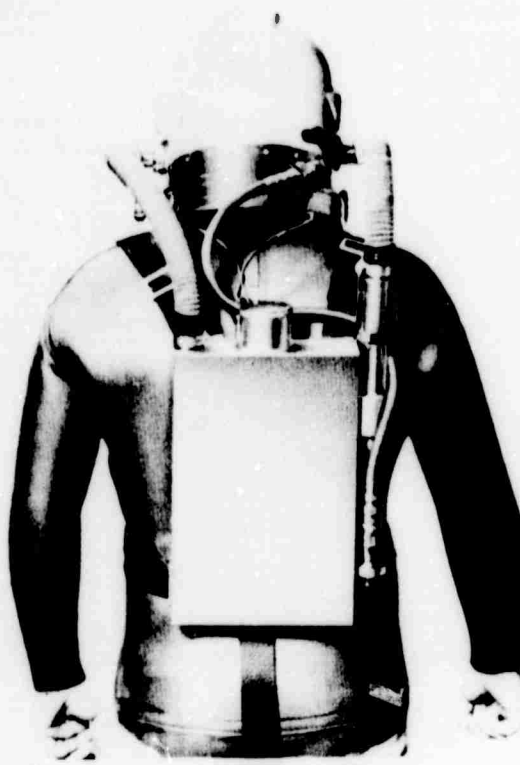
Right Side View   Rear View

Figure 4

Advanced Model 3610 Mixed Gas Diving System
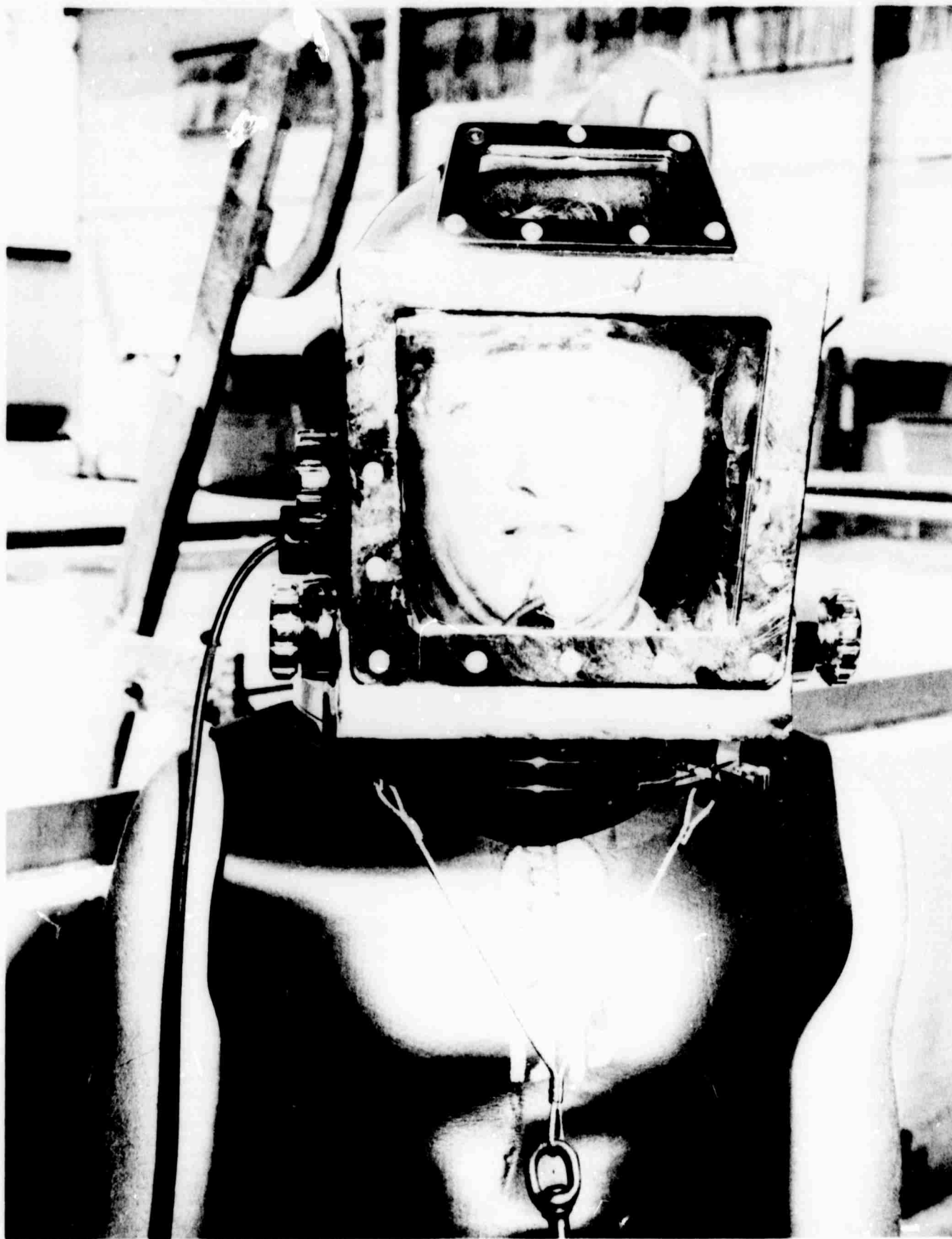
Figure 5: Advanced Model 3000 Mixed Gas Helmet
Note neckseal and jocking arrangement,
Microphone and microphone cable (left) shown
are not standard Advanced equipment.

is rated by the manufacturer for 7 hours (assuming warm water). Silencing of the noise of the aspirator jet is accomplished by inserting a stainless steel scrub-boy in the flow loop just downstream of the venturi (Figure 2, item 3771). The aspirator jet functions at all times gas is supplied to the system. There is no way to shut it off.

The actual equipment tested was an Advanced Model 3000 Mixed Gas Helmet, Serial Number 412 and an Advanced Model 3700 Back Pack Scrubber, no serial number. The helmet was used primarily with standard Advanced neckseals. Limited tests were performed with it used with a modified Dunlop Dry Suit.

The open circuit characteristics of the Model 3000 Helmet were also not tested. Other than for a different location for the air inlet point (above the faceplate directed down versus to the right of the faceplate directed left) the parts of the helmet that would affect its open circuit performance were identical to an Advanced 2000 Open Circuit Air Helmet tested previously (Reference 1). Consequently open circuit testing of the Model 3000 helmet was not considered necessary.

III. SCOPE OF EVALUATION

This evaluation was aimed primarily at determining the ventilation efficiency, noise levels, and diver comfort of the Advanced Model 3610 Mixed Gas (Diving) System when used with a neck seal. Limited ventilation tests (Sections IV. C. 1 and V. C. 1 herein) were performed using the Model 3610 system with a modified Dunlop Dry Suit.

A limited evaluation of the manufacturer-supplied communication system (microphone and 2 helmet speakers) was obtained as a natural by-product of the Subjective Test Dives (Sections IV. C. 2 and V. C. 2 herein). This however was not a major goal of those dives.

Specifically not attempted were, a) a detailed evaluation of the helmet communication system, b) an evaluation of the structural strength of the system, part interchangeability and the ability of the system to withstand normal operational abuse (getting dropped on the deck, tunneling, jetting, etc.), c) use of the helmet system with a breastplate and deep sea dress (constant volume suit) or d) a determination of the expected life of the CO_2 absorbant canister. The testing required to accurately determine the expected canister life amounted to more effort than was considered warranted for the information to be obtained. The helmet is normally used with a neckseal, and the ventilation tests identified above (first paragraph) were considered to represent sufficient testing with constant volume suits.

IV. TEST PROCEDURES

A. Sound Level Tests

1. Apparatus

A test manikin consisting of a soft rubger head and a fiberglass torso was modified to accommodate a Bruel and Kjaer 1-inch condenser microphone and preamplifier at either the right or left ear position. The microphone head was recessed 1/4 inch from the surface of the manikin ear and was connected through appropriate wiring to a B&K sound level meter outside the chamber. Figure 6 shows a simplified schematic diagram of the complete experimental apparatus.

2. Procedure

The helmet was tested dry in NAVXDIVINGU's #5 recompression chamber. The helmet and back pack scrubber were "jocked" (fastened to the test manikin) in a normal diving position. The junction between the helmet neckseal and the manikin's neck was sealed with tape to prevent leaks. Leaks, if present, tended to act as additional sound sources.

The helmet exhaust valve was set at the fully open position, and the helmet gas control valve at the fully closed position. Helmet sound level measurements were taken at 0, 50, 100, 200 and 300 fsw. Both ear positions were tested at 0 and 50 fsw. Only the left ear position was tested at 100, 200 and 300 fsw.

The gas mixtures used were 15% oxygen, 85% helium and air. Air was used at 0 and 50 fsw to simulate an oxygen decompression stop. Air was used instead of oxygen due to safety reasons and the fact that the fluid and acoustical properties of pure oxygen are very nearly identical to those of air. 15% oxygen, 85% helium was used at the 0, 100, 200 and 300 fsw test depths.

Depth
Gauge

Microphone
B&K Type 4131
With B&K
Type 2619
Preamplifier

Helmet

Recirculation
Direction

B&K Microphone
Power Supply
Type 2801

Gas Control
Valve

Neckseal
Exhaust Valve

To
Air Gas
Supply

Supply
Overbottom
Pressure
Gauge

Back Pack Scrubber
(Actually located behind
manikin)

B&K Sound Level Meter
Type 2203 With
B&K Octave Band
Filter Set Type 1613
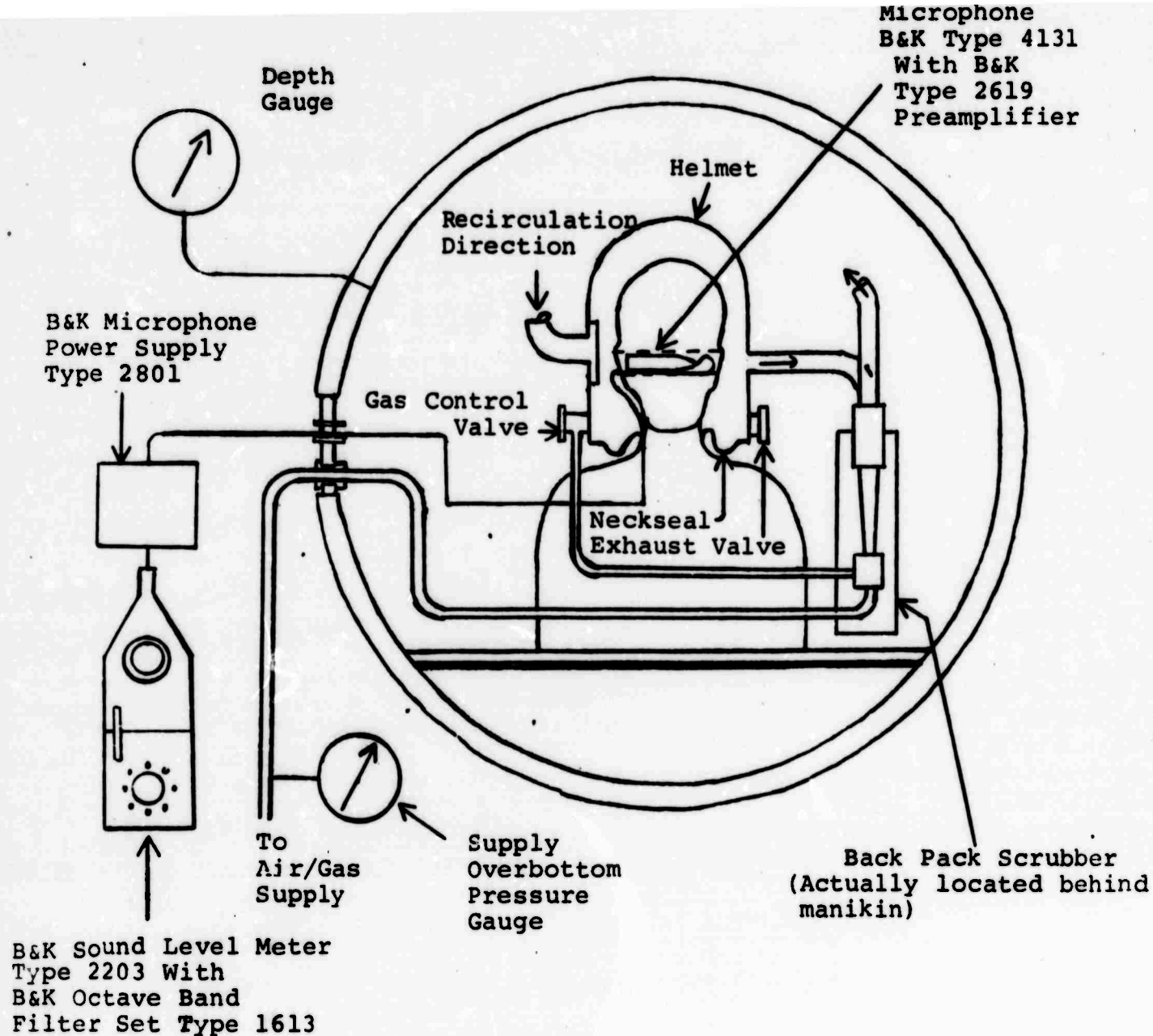
Figure 6

Test Set-Up for Measuring
Sound Levels in the Advanced He-O_2
Diving Helmet

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All sound level tests were conducted with a fresh charge of Baralyme[TM] in the back pack scrubber.

In all cases the **gas** supply pressure was regulated at 100 psi over bottom pressure. The plumbing between the pressure regulation point and the helmet air control valve was approximately equivalent to three 50' sections of standard diver's air hose.

Microphone calibration was checked before and after each test run with a B&K Sound Level Calibrater Type 4230. No changes in microphone calibration were found.

Chamber background noise levels were also tested and found to be insignificant when compared to the measured helmet sound levels.

Octave band sound pressure levels and meter A-weighted sound levels (dBA slow) were taken for all test conditions.

3. Data Handling

The descriptive sound measurement most frequently used to determine noise risk in industry and in the Navy is the A-weighted sound level, dBA. This term also relates closely to the various noise-rating numbers used to describe interference with communications, annoyance and noise fatigue.(4)(5)(6). Unfortunately, calibration curves for the A-weighted sound level measurement at increased ambient pressures as read directly from the sound level meter are not available. It was necessary to first correct the measured octave band sound pressure levels for the microphone sensitivity changes as a result of increased pressure (7)(8)(9) and then determine the equivalent A-weighted

sound levels (dBA) from the equivalent sound level contours shown in Figure 7. This procedure is referred to herein as method one.

The pressure correction factors published by Thomas, Preslar and Farmer for B&K condenser microphones when used in an He-O_2 environment cover only certain specific He-O_2 mixtures (7). However, the procedures used to obtain the published correction factors and other unpublished work (8) provide nearly conclusive evidence that the correction factors contained in reference 7 are accurate for nearly all helium-oxygen mixtures of less than 50% oxygen. The chamber ascent technique used (7) was straight pressure bleed-off (8). Thus the helium percentage on ascent only was almost a constant 98.6% instead of the reported variable percentage. Yet there was no significant change in the microphone calibration from the descent tests where the percentage helium was considerably less. Unpublished tests by Thomas have also indicated no significant difference in the calibration of B&K Type 4132 1" condenser microphones when used at one atmosphere on mixtures of 80/20 (80% helium, 20% oxygen) 85/15; 90/10; 95/5 or 100% helium (8).

Sound levels below 90 dBA could not be handled by method one. For surface tests the A-weighted recordings from the sound level meter were used directly. Under pressure method two described below was used to obtain an approximation of the dBA level.

The contour penetration method (method one) of determining the equivalent A-weighted sound levels is widely used (BUMED, OSHA), and in most cases it works well, especially in cases where the dBA levels are controlled by noise in the 1000 to 4000 Hz center frequency octave bands. This was the case in all the open circuit air helmet tests (1). In those cases, very close

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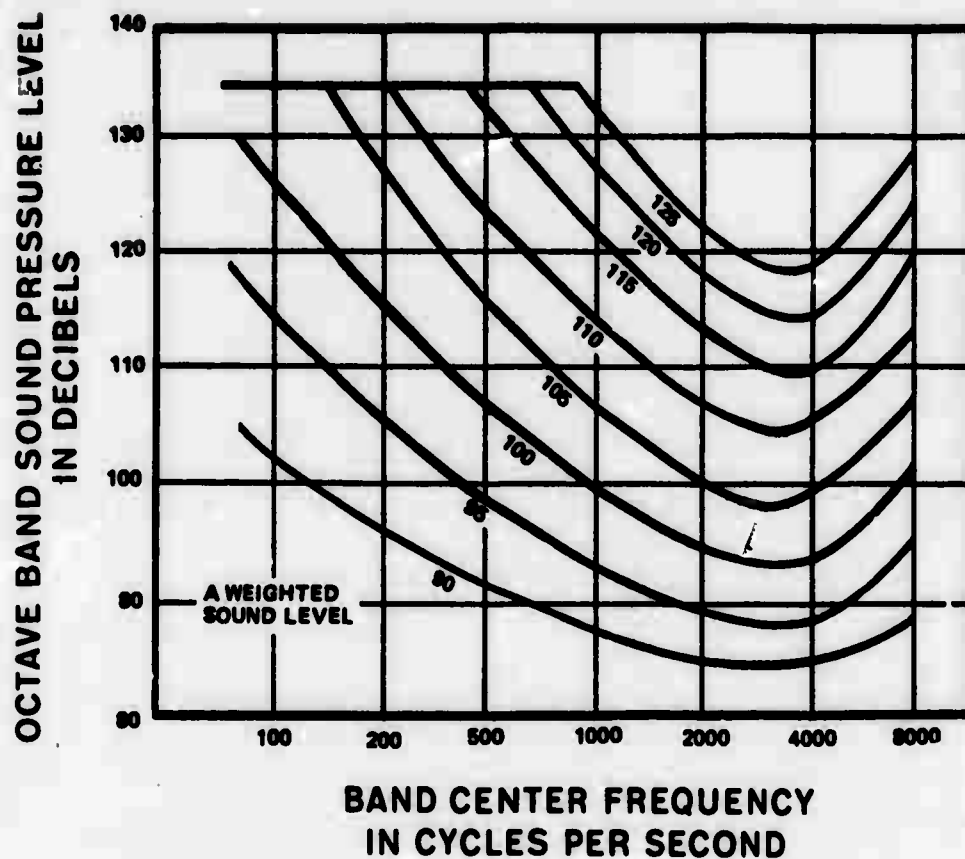
Fig. 7. Equivalent A-Weighted Sound Level Contours. Octave Band Sound pressure Levels May Be Converted to the Equivalent A-Weighted Sound Level by Plotting Them on this Graph and Noting the A-Weighted Sound Level Corresponding to the Point of Highest Penetration into the Sound Level Contours (3).

agreement was obtained between dBA levels calculated by this method and the dBA levels calculated by mathematically exact methods. The mathematically exact methods are accomplished by adjusting the measured octave band sound pressure levels by the appropriate A-weighting factor and then combining the results by the time-consuming, mathematically exact rules for addition of decibel expressed quantities (4)(11)(12).

The contour penetration method, however, breaks down when the dBA levels are controlled by energy in the 125, 250, and 500 Hz center frequency octave bands. It gives dBA levels that are too low (10). Here, the mathematically exact method or equivalent must be used. Under these conditions and when using 1" B&K condenser microphones, very close agreement with the mathematically exact method can be obtained by simply adding to the dBA reading from the sound level meter the microphone pressure correction factor for low frequencies. This occurs because for the B&K 1" condenser microphones, the pressure correction factors are essentially equal (to within 1 dB or less) for all octave bands with center frequencies up to and including 2000 Hz on air and up to and including 4000 Hz on helium-oxygen mixtures (7)(9). This procedure is referred to herein as method two.

The point where one must use one of the latter methods (method two or the mathematically exact method) occurs when the measured sound pressure levels in the octave bands with center frequencies at 125, 250, and 500 Hz exceed the measured sound pressure levels in the octave bands with center frequencies at

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1000, 2000 and 4000 Hz by more than their A-weighted correction factors. These are 3.3 dB for the 500 Hz, 8.7 dB for the 250 Hz, and 16.2 dB for the 125 Hz center frequency octave bands (4).

For the tests conducted herein the measured sound pressure levels in the 250 Hz center frequency octave bands were generally 8 to 15 dB higher than those in the 1000 Hz center frequency octave bands. Consequently both methods one and two were used for comparison purposes.

B. Ventilation Tests

    1. Apparatus

Figure 8 shows a schematic diagram of the test set-up used for these tests.

The test manikin shown consisted of a head of ¼" soft rubber over a sawdust and epoxy resin core and a fiberglass torso. It contained internal tubing to allow it to breathe like a working diver when connected to an external breathing machine as shown. The internal tubing was arranged such that the ratio of oral flow to nasal flow was approximately 2 to 1. The manikin also contained additional internal tubing to allow 4 gas samples and 1 pressure reference to be taken from inside the helmet without having to penetrate or disturb the helmet itself. The pressure reference point was in the center front of the manikin's chin. The gas sample openings were 2 below each ear, and they carried fittings to allow extension tubing or caps to be added as desired. This was done whenever a sample was desired from a location other than immediately below the manikin's ears. Two eyebolts fastened to the torso base front and rear were provided as anchor points for the various helmet "jocking" systems.

The test box was made of ½" acrylic plastic in the shape of a regular hexagonal cylinder 5' high by 33" internal diagonal. The main lid was removed only when changing helmets or working on equipment inside the box. A smaller armhole was used for helmet valve adjustments and minor internal repairs.

SYMBOL KEY

⊗ Needle Valve

▯ Flowmeter

⊕ Pressure Guage

Double Hose
SCUBA Mouthpiece

Differential Pres-
sure Transducer

⊞ Non-Return Valve

▮ Solenoid Valve

• CO_2 Sample Point

YSI Thermistor Read-Out

Beckman IR-215 CO_2 Analyzer

LB-1 CO_2 Analyzer

Esterlyne Angus 1-Channel Strip Chart Recorder

HeO_2 Supply Regulated at 100 psi Over Bottom Pressure

LP Air

Depth Gauge

Brush Carrier Preamplifiers Model 13

Brush 220 2-Channel Strip Chart Recorder

Hyperbaric Chamber

CO_2 Supply Regulated at 700 psig

Adjustable Pressure Reference Tube

Test Box

Dry Gasometer

3 liter mixing box

Heat & Humidity Chamber

Piston Drive

Breathing Machine

6"

Figure 8: Schematic, Ventilation Efficiency Test Apparatus for He-O2 Helmets, 1970-1971. Numbers Refer to CO_2 Sample Lines, Letters to Pressure Transducers

The loop in the plumbing between the breathing machine and the manikin was used to obtain a more uniform CO_2 concentration in the manikin's exhaled breath. Without the loop the CO_2 had to move from its addition point at the breathing machine to the manikin's mouth by diffusing through an oscillating column of gas. This resulted in a heavy concentration of the expired CO_2 toward the end of the expiration cycle. This situation occured because the necessity (and convenience) of having the breathing machine outside the pressure boundary resulted in long hoses with an internal volume in excess of the 2 liter tidal volume provided by the breathing machine. With the arrangement shown the volume of the oscillating (net flow equal only to the CO_2 addition rate) gas column between the loop (uni-directional flow) and the manikin's mouth was reduced to approximately 140 cc. This was the volume of the breathing system tubing internal to the manikin. With the system shown the volume (or length) of the hoses used in the breathing loop and the volume of the plumbing between the breathing machine and the breathing loop have negligible effect on the expired CO_2 profile. They affect only the mechanical (hose stretch) and pneumatic (air compressability) compliance of the breathing system and its CO_2 concentration time constant (the length of time for CO_2 concentrations to reach equilibrium or steady state). Total breathing loop volume was approximately 5.5 liters.

A sample of the CO_2 profile leaving the mixing box with this system is contained in Appendix A. The time

required for CO_2 levels to reach equilibrium (steady state)
with this system was about 5 minutes. The errors introduced by
the mechanical and pneumatic compliance of the breathing loop
plumbing were small and could safely be neglected. These errors
affected only the maximum and minimum breathing pressures produced
in the helmet, and their effect was to reduce the peak pressures
produced. The worst case peak reduction which occured at the
surface (0 fsw) where the pneumatic compliance was greatest was
estimated at less than 10%.

The measurement range of the CO_2 analysers used was 0 to
0.5 per cent by volume for the Beckman IR 215 Analyser and 0 to
5.0 per cent by volume for the Beckman LB-1 Analyser.

Number 1 CO_2 sample line (Figure 8) was placed in the center
of the manikin's mouth. CO_2 sample lines numbers 2, 3 and 4
(Figure 8) were set to draw samples from respectively the back
pack suction hose, the back pack return hose and the exhalation
mixing box. All samples were drawn by open ended 1/16" I.D.
tubes or fittings. The solenoid on the number 1 sample line
was controlled by a micro-switch on the breathing machine piston
drive. It was set to allow a sample to pass only during manikin
inhalation. Sample lines 2, 3 and 4 were arranged to draw a
continuous sample when in use.

Differential pressure transducer A (Figure 8) was a 5 PSID
Statham transducer set up to measure the pressure in the helmet
relative to water pressure at the level of the manikin's supra-
sternal notch (20 cm. below mouth center line). The water

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pressure reference tube was kept clear of water by air added
from an LP source at a rate sufficient to produce a tiny, but
steady stream of bubbles from its open end as shown in Figure 8.
The bubble stream was monitored by visual observation, and its
presence did not effect the accuracy of the measured pressures.

Differential pressure transducer B (Figure 8) was a 1 PSID
Statham transducer set up to measure the pressure head (pressure
rise) generated by the venturi.

2. Procedure

The following were the controlled variables and the
values at which they were controlled:

depth	0, 50, 100, 200, 300, 400, 500, 600, 750 fsw
breathing media	air, 20% HeO_2, 3% HeO_2
breathing machine:	
tidal volume	1.0 liters per breath
breathing rate	30 breaths per minute
CO_2 add rate	1.2 slpm
waveform	modified sinusoid with exhalation to inhalation time ratio of 1.1 to 1.0
supply pressure	100 psi overbottom pressure measured at the inlet to the non-return valve.

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valve positions:

exhaust valve	fully closed, 1/3 (1 turn) open
air control valve	fully closed
helmet position on manikin	normally jocked position with manikin head looking straight ahead.

exhaled gas:

humidity	saturated at room temp.
temperature	room temp. (approx $70^{\circ}F$)

The following were the measured variables:

helmet pressure relative to water pressure at the level of the manikin's suprasternal notch (20 cm. below the mouth center)

pressure rise generated by the venturi

helmet gas consumption

recirculation (back pack) flow rate

helmet internal temperature

CO_2 levels at the following locations:

1. at center of manikin's mouth

2. back pack suction hose

3. return hose from the back pack to the helmet

4. outlet of exhalation mixing box

The procedure was to set the helmet air control and exhaust valves at the desired positions (air control valve always closed) and then proceed through the depth and gas mixture conditions in the following order:

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	Depths	Gas Mixtures
Test Run	0, 50, 100 fsw:	air
#1	100, 200, 300, 400	
	500, 600, 750	
	50 and 0 fsw	3% HeO_2
Test Run	0, 50, 100, 200,	20% HeO_2
#2	100 and 50 fsw	

Two complete preliminary runs were undertaken for the purposes of operator familiarization and equipment and procedure de-bugging prior to the 2 test runs described above.

All CO_2 sample lines were secured whenever pressure measurements were being made.

The selection of the breathing rate and tidal volume parameters was influenced as much by practical considerations as it was by physiological considerations. Previous tests of neckseal type air diving helmets at 25 breaths per minute and a 2.0 liter tidal volume (50 liters per minute respiratory minute volume (RMV)) had revealed a distressing tendency of those helmets to take on water under those conditions, especially at 200 fsw (1). Experience with neckseal type recirculating helmets had revealed a similar tendency at 15 breaths per minute and a 2.0 liter tidal volume (30 lpm RMV). These leakage problems were observed to essentially disappear when the respiratory parameters were changed to a 1.0 liter tidal volume at 30 breaths per minute (30 lpm R'IV). Consequently the latter parameters were used for these tests. The helmet peak pressure data recorded during these tests and similar data obtained during the tests of the Advanced Air Helmet (1) confirmed that helmet leakage and ultimate flooding would have been likely had the 2.0 liter tidal volume been used. (Peak inhalation

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pressures of greater than -25 cm H_2O were generally observed to result eventually in a flooded helmet.) As a further precaution against flooding, the seal between the helmet neckseal and the manikin's nect was augmented with Band-Aid[TM] Skin Tape.

Dry gasometers were normally used to measure the net flow through the helmet system (gas consumption) and the flow through the canister (recirculation rate). Whenever possible, the gas consumption rate was also determined by timing the pressure drops in the supply gas storage bottles. This was the only method that could be used at 400 fsw and below due to leaks at those depths in the lid seals on the test box.

All transducers, CO_2 analysers and recorders were calibrated daily and immediately prior to any major test. No significant changes in calibration were found to occur. The differential pressure transducers and their recorder were calibrated against a water manometer; the CO_2 analysers and the Esterlyne Angus recorder were calibrated against gases of known CO_2 concentrations. The dry gasometer and flowmeters were factory calibrated. The thermistor was calibrated against room temperature.

3. Data Handling

The values of the measured parameters are tabulated in Tables 2 and 3. The measured CO_2 values were also cross-checked for consistency and conservation of CO_2. The general results of these cross-checks are discussed in Section V. B. The detailed results are contained in Appendix A, Tables A-1 and A-2.

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C. Manned Tests

   1. Bicycle Ergometer Ventilation Tests

      a. General

            These tests were conducted as part of a dry
300 foot equipment evaluation/saturation training dive con-
ducted at NAVXDIVINGU in March 1971. In general terms the
test subjects were asked to donn a particular piece of diving
equipment and then ride a standard laboratory bicycle ergometer
located in NAVXDIVINGU's #5 wetpot for specified times at speci-
fied work rates. Several pieces of diving equipment were tested.
This section details the tests that were performed with the
subjects using the Advanced Mixed Gas Diving System.

      b. Apparatus

            Figure 9 shows a schematic of the test apparatus
used for these tests. Figure 10 shows one of the test subjects
riding the bicycle ergometer. Figure 11 shows a close-up of
the helmet under test as it was worn with a neckseal by one of
the test subjects.

            Tests were conducted with the helmet used with a
neckseal (Fig. 11) and also with it used with a constant volume
dry suit. The constant volume suits used were Dunlop dry suit
cut off at the waist to prevent the subjects from suffering
excessive overheating. (Chamber temperature was a balmy 85-88°F).
To effect a seal, the suits were taped to the subject's waists
with standard surgical adhesive tape.
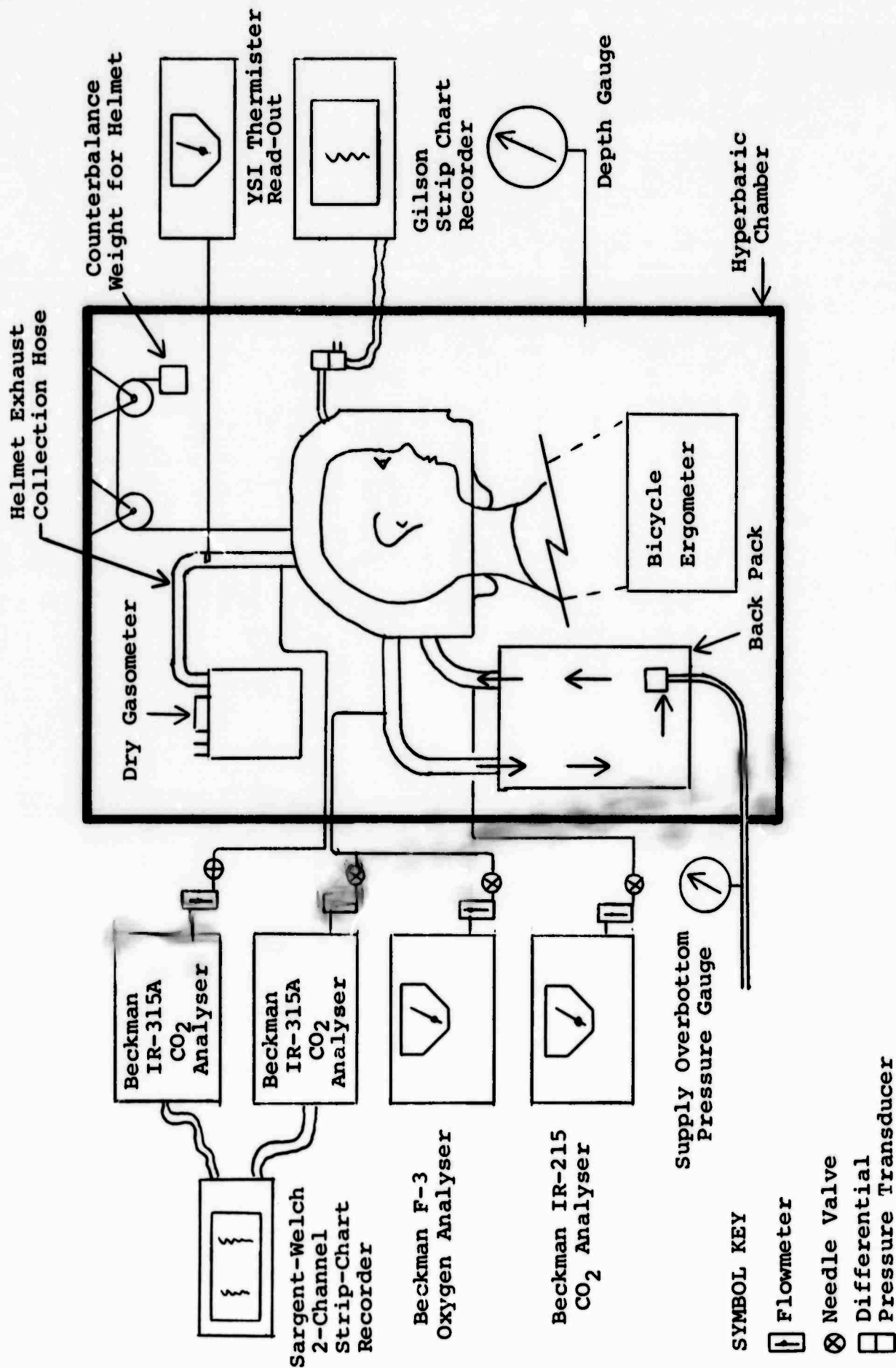
Figure 9   Schematic, Bicycle Ergometer Ventilation Test Apparatus for He-O₂ Helmets, March, 1971

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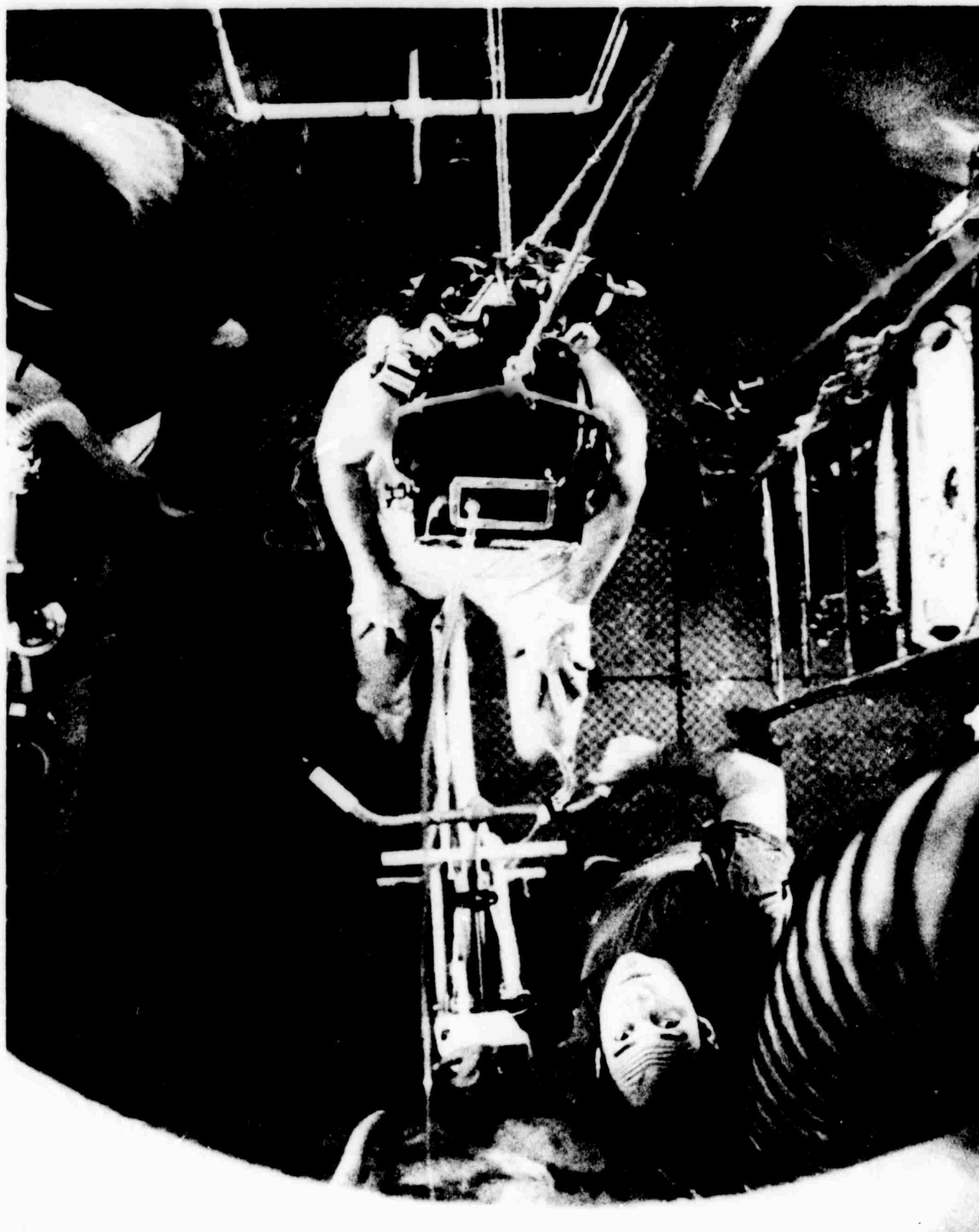
Figure 10   Test Subject Riding the Bicycle Ergometer
Note the ropes and weights of the helmet counterbalance system
and the collection hose from the helmet exhaust to the dry
gasometer.

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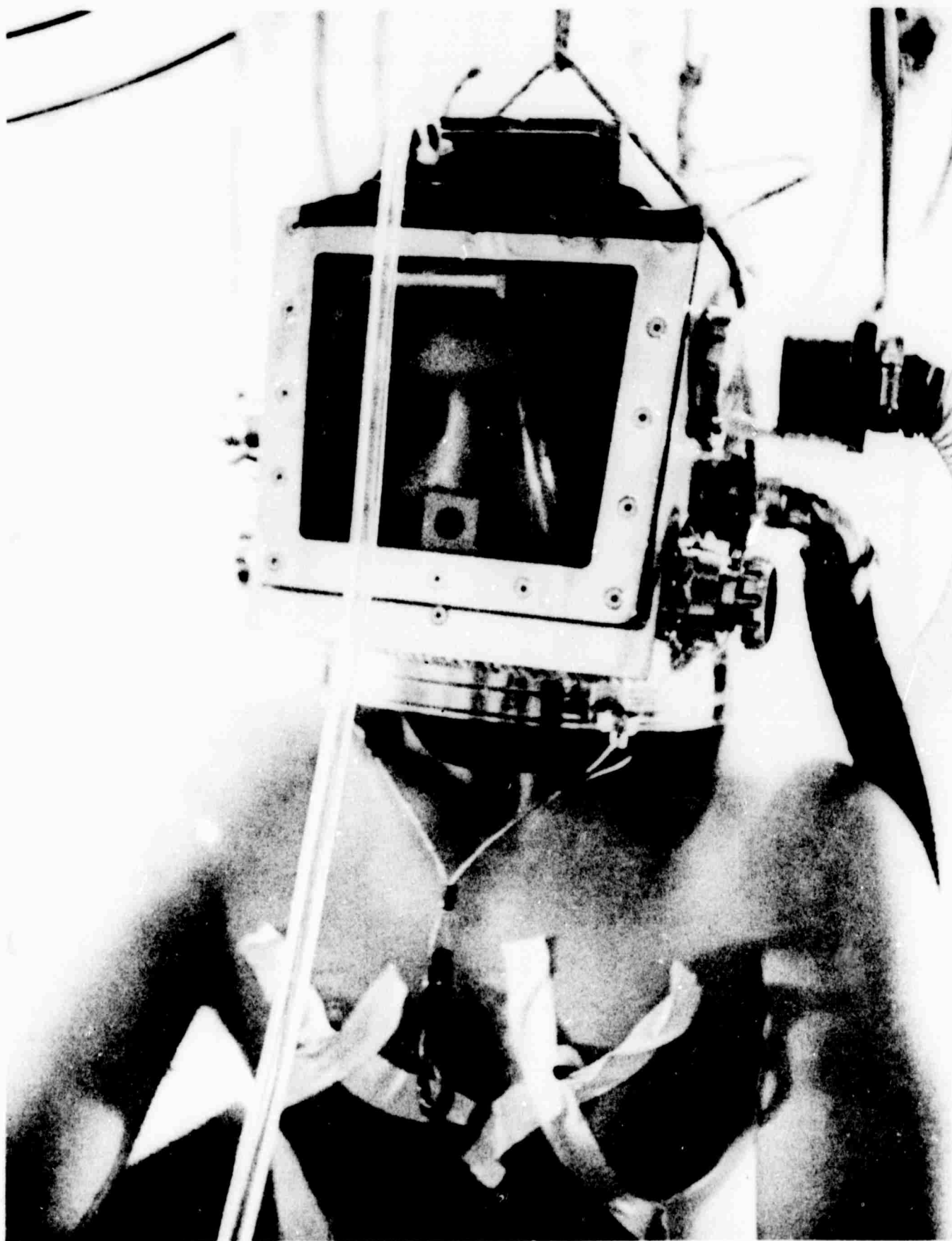
Figure 11   Advanced Mixed Gas System on a Test Subject
Note rope from helmet counterbalance system, exhaust collection
hose and clear plastic hose to pressure transducer.

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To relieve the weight on the subjects, the helmet and back pack were supported by a counter-weight system as shown in Figures 9 and 10.

The net flow through the system (i.e. system gas consumption) was measured by collecting the effluent gas from the helmet exhaust valve and passing it through a dry gasometer (Figures 9, 10 and 11). This arrangement worked only sporadically when the subjects were using neckseals. It was completely unreliable when they were using the modified dry suits. In that case leaks, always a problem even with the neckseals, became almost impossible to control. This method of measuring helmet gas consumption rates has since been abandoned in favor of rotameter type flowmeters in the gas supply system.

The helmet internal pressure relative to chamber pressure was monitored by a Statham 1 PSID differential pressure transducer and recorded on a Gilson multi-channel recorder.

CO_2 and O_2 levels were monitored by the instruments shown in Figure 9. The measuring ranges of the instruments were 0-1% by volume for the IR-315A CO_2 analysers, 0 to 0.5% by volume for the IR-215 CO_2 analyser and 0-25% by volume for the F-3 oxygen analyser. The readings from the IR-315A analysers (helmet exhaust and canister suction CO_2 levels) were recorded on a wide channel Sargent Welch recorder as shown.

Back pack flow was not monitored during the actual bicycle tests. It was measured once at each test depth by removing the helmet from the test subject, tying off the neckseal

and inserting a second dry gasometer in the canister suction hose as in Figure 8.

    c. Procedures

The following were the controlled variables and the values at which they were controlled:

depth	10, 200 and 300 fsw
work rate	nominally 60, 90 and 120 watts; 51, 81 and 113 watts by actual calibration (18)
time at each work rate	6 minutes
gas mixture	30% HeO_2 at 10 fsw, 16% HeO_2 at 200 and 300 fsw
supply over bottom pressure	100 psi
supply valve position	closed
exhaust valve position	subject's choice
mode of helmet use	dry suit, neckseal

The following were the measured variables:

helmet pressure relative to chamber pressure
helmet gas consumption (assumed equal to exhaust rate)
oxygen content in the helmet
CO_2 levels at the following locations:
  1. exhaust collection hose
  2. canister suction hose
  3. canister return hose
helmet exhaust gas temperature

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A "surface control" run was conducted at 10 fsw. However, due to time considerations, only limited data was taken: gas consumption and helmet pressure data for 2 of the 4 test subjects. However all subjects had at least 2 complete practice sessions on the bicycle prior to dive commencement.

Full test runs were conducted at 200 fsw with subjects Huckins and Waddell using the Advanced Mixed Gas Helmet with a neckseal. No dry suit runs were attempted at 200 fsw. At 300 fsw full test runs were accomplished by subjects Waddell, Brewer and Davis using the helmet with a neckseal and by subjects Huckins and Davis using it with a dry suit.

Each test consisted of an 18 minute period composed of 3 six-minute work periods with no breaks in between. During the first 6 minute period the subject performed work at a rate of 51 watts mechanical; during the 2nd, 81 watts mechanical; and during the third, 113 watts mechanical. These work rates correspond roughly to oxygen consumption rates of 1.0, 1.5 and 2.0 liters per minute, STPD (18). All measurements were made during the last minute of each 6 minute work period.

All transducers, gas analysers and recorders were calibrated daily and immediately prior to any major test. No significant changes in calibration were found to occur. The differential pressure transducer and its recorder were calibrated against a water manometer; the O_2 and CO_2 analysers and the Sargent-Welch recorder against gases of known concentrations. The dry gasometers and flowmeters were factory calibrated. The thermistor was calibrated against room temperature.

d.   Data Handling

From the measured values reported above the divers'
indicated oxygen consumption and carbon dioxide production were
calculated. These were then checked for consistency within
themselves and with data from the same subjects performing the
same work rates on the same saturation dive using a Kirby-Morgan
KMB-8 Bandmask (17). These crosschecks resulted in the measured
oxygen readings being thrown out for reasons detailed in Section
V. C. 1.

The values of the measured variables and the cal-
culated CO_2 production rates are tabulated in Tables 5, 6 and 7.

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2. Subjective Test Dives

   a. Apparatus and Procedures.

These tests were all conducted in NAVXDIVINGU's #5 and #6 wetpots. The oxygen level in the canister suction hose and the carbon dioxide level in the canister return hose were monitored by Beckman F-3 and IR 315A analyzers respectively. The samples were transmitted to the analyzers via 1/32" I.D. tubing approx. 20 feet in length.

The helmet was supplied with gas from the gas control board at 100 psi overbottom pressure whenever mixed gas was being used and at 50 psi overbottom pressure when oxygen was being used. The piping between the pressure regulation point and the inlet to the helmet non-return valve consisted of 30 feet of 3/4" I.D. pipe, three 3/4" CPV globe valves (all fully open) and 50' of 3/8" I.D. medium pressure hose.

Water temperature for all dives was maintained at a level comfortable to the divers, usually about 80°F.

Normal U.S. Navy diving procedures were followed. While on the bottom the divers alternated between 10 minute periods of moderate work and 5 minute rest periods. The work the divers were asked to perform alternated between lifting a 70-pound weight (78 lbs dry) a distance of 2 1/2 feet 10 times per minute and swimming against a trapeze designed to exert a steady backward force of 6.0 lbs. For an average diver, exerting a stationary swimming force of 6.0 lbs. produces an oxygen demand of approximately 1.26 standard liters per minute (19). This is equivalent to a respiratory minute volume of approximately 30 liters per minute (20) or to swimming in SCUBA at a steady speed of approximately 0.8 knots (19) (20).

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Twenty manned dives were conducted using the helmet (Model 3000, Serial Number 412) with a standard advanced backpack and standard advanced neckseals. Ten different divers were used.

Table 1 lists the depths and bottom times used.

Depth/Bottom Time (fsw/minutes)	Number of Dives
60/30	2
60/40	1
60/45	3
60/50	3
60/60	1
60/120	1
150/20	1
150/30	2
230/20	4
300/15	2
	20

Table 1

Depth-time Breakdown for Subjective Test Dives conducted with the Advanced Mixed Gas Diving Helmet.

    b.   Data Handling

Oxygen and carbon dioxide level readings were taken every 5 minutes during all dives. After each dive the divers were asked to complete a subjective analysis questionnaire on the helmet, representative copies of which are found in Appendix C.

V. RESULTS AND DISCUSSION

A. Sound Level Tests

Table 2 lists the octave band sound pressure levels and the equivalent dBA sound levels obtained from the Advanced Mixed Gas Diving System.

Figure 12 lists the currently accepted noise exposure limits.

A comparison of Figure 12 with Table 2 indicates that the sound levels existing in the Advanced Mixed Gas System, when used in the venturi mode, are into the damage risk levels under most of the conditions tested. The conditions tested are considered to be representative of most normal He-O_2 diving situations. The measured sound levels are however not into the damage risk level far enough to preclude normal helium-oxygen diving operations provided that precautions are taken to avoid excessively long exposures.

The measured sound levels are however high enough, particularly in the lower frequencies, so that some interference with communications can be expected.

Open circuit sound levels occuring in the system were not measured. It can be safely assumed that the open circuit air and oxygen sound levels will be comparable to those existing in the Advanced Model 2000 Air Diving Helmet (92-102 dBA, reference 1) since the open circuit equipment in the two helmet models is nearly identical. Open circuit He-O_2 operating time is short, and experience with similar equipment has indicated that, within the same helmet type, the open circuit He-O_2 sound levels are comparable to the open circuit air sound levels (14).

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OCTAVE BAND SOUND PRESSURE LEVELS IN DB RE 0.0002 MICROBAR AT THE INDICATED CENTER FREQUENCIES IN HERTZ

DEPTH FSW	GAS	OVER BOTTOM PRESSURE PSI	31.5	63	125	250	500	1000	2000	4000	8000	16000	dBA EQUIVALENT METHOD 1	METHOD 2
						RIGHT	EAR							
SURFACE	AIR	100	99	88	96	89	82	81	82	81	74	59	89*	89
50	AIR	100	94	86	98	91	80	78	77	74	74	59	<90	88
						LEFT	EAR							
SURFACE	AIR	100	94	86	97	90	88	82	81	77	75	60	90*	90
100	15% HeO2	100	90	92	99	99	89	89	83	81	76	63	92	94
100	15% HeO2	100	81	88	94	99	88	87	78	76	78	-	92	93
200	15% HeO2	100	87	92	95	100	91	85	75	73	76	-	93	93
300	15% HeO2	100	89	91	95	99	90	85	74	72	73	-	92	93

*Direct from sound level meter

Table 2

Sound Levels, Advanced Mixed Gas Diving System, Model 3610 System tested dry with helmet exhaust valve set at fully open. Data taken 10 October 1970.

ALLOWABLE NOISE EXPOSURE PER DAY	
TIME (HRS)	SOUND LEVEL dBA
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
¼ OR LESS	115

FIGURE   12

Currently Accepted Daily Noise Exposure Limits (3)(4)

The tests conducted herein were all conducted with the helmet dry. At this point there are no mixed gas helmets that have been tested for sound levels both wet and dry. Open circuit air helmets, when submerged, exhibit increases in their measured sound levels from none to 5 or 6 dBA depending the type of helmet (10, 13, 14, 15). The increases are believed to be due to bubble and possibly exhaust valve noise. Since He-O_2 helmets produce relatively little exhaust gas, it is felt that their submerged sound levels will be little, if any, higher than their dry sound levels.

The helmet gas consumption and recirculation rates were not measured during these tests. It can be safely assumed however that they are approximately equal to the gas consumption and recirculation rates reported in Sections V. B and V. C.1. herein since the conditions producing them were comparable.

The damage risk levels (Figure 12) have been developed for exposures in 14.7 psia air, and their applicability under increased ambient pressures has not yet been substantiated. There is some reason to believe that the ear may tolerate higher noise levels at increased ambient pressures (2, 16). There are, however, at least three documented cases where maximum exposures (Figure 12) to damage risk level noise under conditions of high ambient pressures have produced significant temporary hearing impairments (2). This suggests that the damage risk criteria should be considered accurate for high ambient pressures until such time as they are either demonstrated inaccurate in that application or are replaced by a subsequent standard.

The data presented in Table 2 is not sufficiently extensive to permit the establishment of firm exposure times in the helmet based solely on the listed sound levels. Further testing would be required before that could be done. However, until that time, it is considered advisable not to exceed the maximum daily exposures indicated by comparison ot Table 2 with Figure 12, less ½ hour. The ½ hour reduction is to allow for the effects of the short periods of open circuit operation normally encountered in He-O_2 diving. This will mean, in most circumstances, restricting a diver's time in the helmet to not more than 4 hours per 24 hour period. This may have to be reduced further if the diver is exposed to high noise levels in his non-diving work as well.

If it is desired to compute the maximum allowable exposure to noise of varying levels, the following formula may be used (3)(4):

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots \frac{Cn}{Tn} \leq 1$$

Where $C_1 \ldots Cn$ are the actual durations of exposure at the noise levels with duration limits $T_1 \ldots Tn$ as defined by Figure 12. Reference 3, BUMED INST. 6260.6B, Navy Dept., Hearing Conservation Program, should be consulted if it is found necessary to use this formula.

There is sometimes a wide variability in the measured sound levels between air helmets of the same type (2)(10). So far there has been insufficient testing of venturi type helium-oxygen helmets to determine if the same variability exists in them. The two He-O_2 helmets of the same type for which there is data exhibited very similar sound levels (10). In the venturi type helmets

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most of the components that have significant effect on the sound level, venturi, ducting, etc. are fixed and relatively free from abuse. Consequently it is reasonable to assume, until proven otherwise, that there is not significant variation in the sound levels between helium-oxygen helmets of the same type. If such variability is demonstrated, the exposure limits expressed above may have to be reduced.

B. Breathing Machine Ventilation Tests

Tables 3 and 4 present the complete data taken on the two test runs. Figures 13, 14 and 15 present the more important data in graphic form. Figure 13 gives plots of the helmet gas consumption and the total helmet flow rate. The total helmet flow rate is the sum of the gas consumption and recirculation rates listed in Tables 3 and 4. Figure 13 also contains the flow rate data obtained under Sections V. C. 1. Figure 14 gives a plot of the peak inhalation and exhalation pressures; Figure 15, the cannister inlet and outlet CO_2 levels.

Figures A-2 and A-3 of Appendix A contain representative samples of the pressure and CO_2 recorder tracings obtained during these tests.

As can be seen in Tables ·3 and 4 and in Figure 13, the helmet provides ample flow thorughout most of the depths tested. There is no accepted minimum helmet flow rate for mixed gas helmets. However the 4.5 acfm ventilation rate widely accepted for air helmets (25) is considered also to be a reasonable minimum level for recirculating type helmets. The flow rate through the Advanced Mixed Gas helmet exeeeds that level throughout the 0 to 300 foot water column where the helmet would normally be used.

The asymptotic forms of the gas consumption and recirculation rate curves (Figure 13) are typical of venturi powered recirculating type helmets. So are the ratios of recirculation flow to gas consumption listed in Tables 2 and 3. (21)(22)(23).

The transducer monitoring the pressure rise across the venturi was repeatedly checked for calibration and found to be

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Depth (fsw)	0	50	100	100	200	300	400	500	600	750	50	0
Respiratory Rate (breaths per minute)	15	15	15	15	15	15	15	15	15	15	15	15
Tidal Volume (liters per breath)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Gas Composition	100% He	100% He	100% He	38 HeO_2	38 HeO_2	38 HeO_2	38 HeO_2	38 HeO_2	38 HeO_2	38 HeO_2	38 HeO_2	38 HeO_2
CO_2 Addition Rate (slpm)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Gas Consumption (cfm)*	3.4	2.82°	.99	.92 / .91	.71 / .70	.56 / .55	.42 / .33°	- / .56	- / .47	- / .38	1.1 / 1.2	2.9
Recirculation Rate (cfm)	16.9	11.3	9.2	8.5	6.4	5.6	4.9	4.5	3.8	3.7	9.9	16.9
Ratio: Recirculation to Consumption	5.0	-	9.3	9.3	9.1	10.1	11.7	8.0	8.1	9.7	8.6	5.8
Peak Exhalation Pressure (cm. H_2O)	+60	+41	+39	+42	+41	+42	+40	+39	+37	+38	+40	+44
Peak Inhalation Pressure (cm. H_2O)	+36	-4	-15	-12	-20	-22	-23	-25	-25	-25	-5	+20
Venturi Pressure Rise (cm. H_2O)	4	4	4	4	4	3	3.5	3.5	3.5	4	3	3
Inspired PCO_2 (% S.E.)	.3	.36	.37	.51	.55	-	-	-	-	-	.56-.79	-
Canister Outlet PCO_2 (% S.E.)	.06	.12	.07	.12	.13	.23	.18	.10	.26	.32	.19	.18
Canister Inlet PCO_2 (% S.E.)	.26	.36	.49	.51	.60	.68	.73	.90	.90	1.22	.56	.37
Expired PCO_2 (% S.E.)	4.95	4.59	4.63	4.51	4.52	4.44	4.44	4.45	4.96	5.91	4.47	>5.0
Helmet Gas Temperature (°F)	78	86	86	86	86	85	-	84	84	-	-	-

← CONTROLLED VARIABLES | MEASURED VARIABLES →

* Gasometer method unless 2 values are shown. If 2 values are shown, gasometer method value is the top value; pressure drop method value, the lower value.
o Operator reading error suspected; value not used in calculations.

Table 3. Breathing Machine Ventilation Test Results: Advanced He-O_2 Diving Helmet
23 February 1971, Test #1

Depth (fsw)	0	50	100	200	100	50
Respiratory Rate (breaths per minute)	15	15	15	15	15	15
Tidal Volume (liters per breath)	2.0	2.0	2.0	2.0	2.0	2.0
Gas Composition	20% HeO2	20% HeO2	20% HeO2	20% HeO2	20% HeO2	20% HeO2
CO_2 Addition Rate (slpm)	1.2	1.2	1.2	1.2	1.2	1.2
← CONTROLLED VARIABLES						
Gas consumption (cfm)*	1.69	1.06 / .98	.71 / .74	.64 / .490	.78 / .73	1.13 / .97
Recirculation Rate (cfm)	11.3	7.8	6.4	5.3	6.2	7.8
Ratio: Recirculation to Consumption	6.9	7.6	8.8	9.4	8.2	7.4
Peak Exhalation Pressure (cm. H_2O)	-8	44	42	46	42	42
Peak Inhalation Pressure (cm. H_2O)	-18	-4	-12	-18	-12	-04
Venturi Pressure Rise (cm. H_2O)	3	4	4	4	4	4
Inspired PCO_2 (% S.E.)	-	.75	.84	1.01	.90	.75
Canister Outlet PCO_2 (% S.E.)	.10	.15	.24	.21	.22	.18
Canister Inlet PCO_2 (% S.E.)	.42	.60	.81	1.01	.74	.64
Expired PCO_2 (% S.E.)	5.1	5.15	5.24	5.79	4.75	4.92
Helmet Gas Temperature (°F)	81	82	78	80	68	-

MEASURED VARIABLES ↓

* Gasometer method unless 2 values are shown. If 2 values are shown, gasometer method value
  is the top value; pressure drop method value, the lower value.
○ Operator reading error suspected; value not used in calculations.

Table 4 Breathing Machine Ventilation Test Results: Advanced He-O_2 Diving Helmet,
         23 February 1971. Test #2
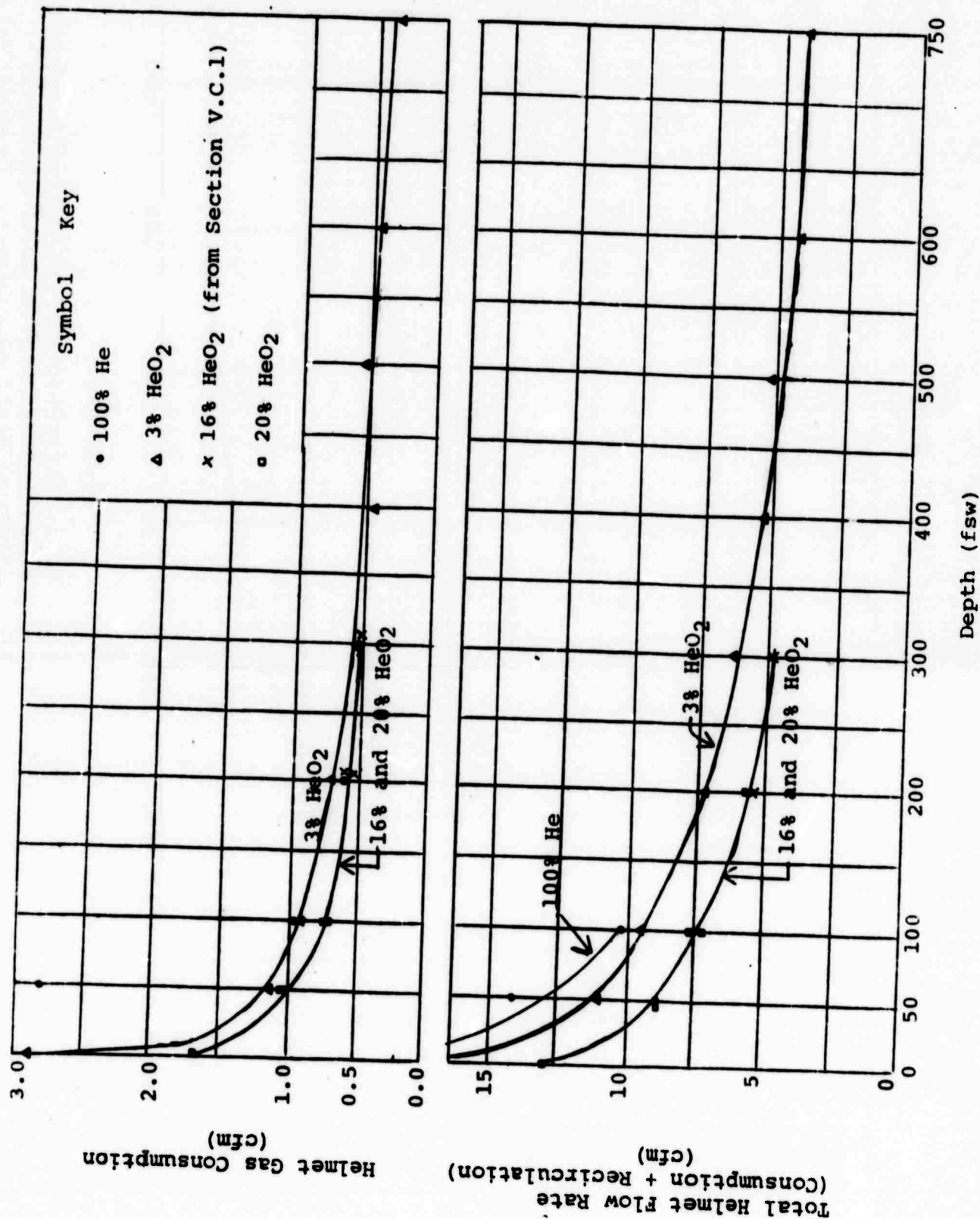
Figure 13   Helemt Gas Consumption and Total Helmet
Flow Rate, Advanced Mixed Gas Helmet
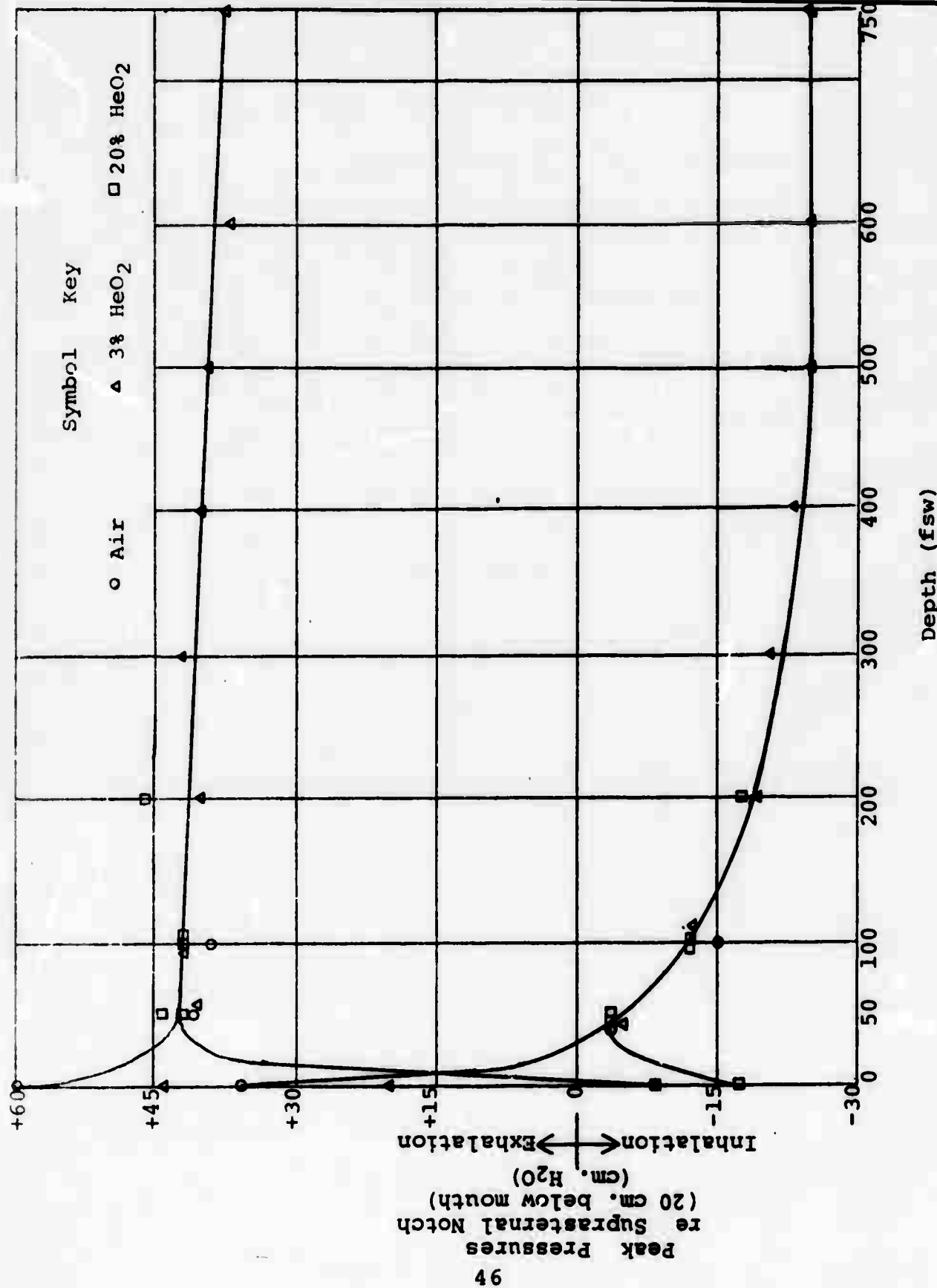
45

Figure 14   Peak Inhalation and Exhalation Pressures
Breathing Machine Ventilation Tests,
Advanced Mixed Gas Helmet. Exhaust Valve
One Turn OPEN, 30 Breaths Per Minute
1.0 Liter Tidal Volume

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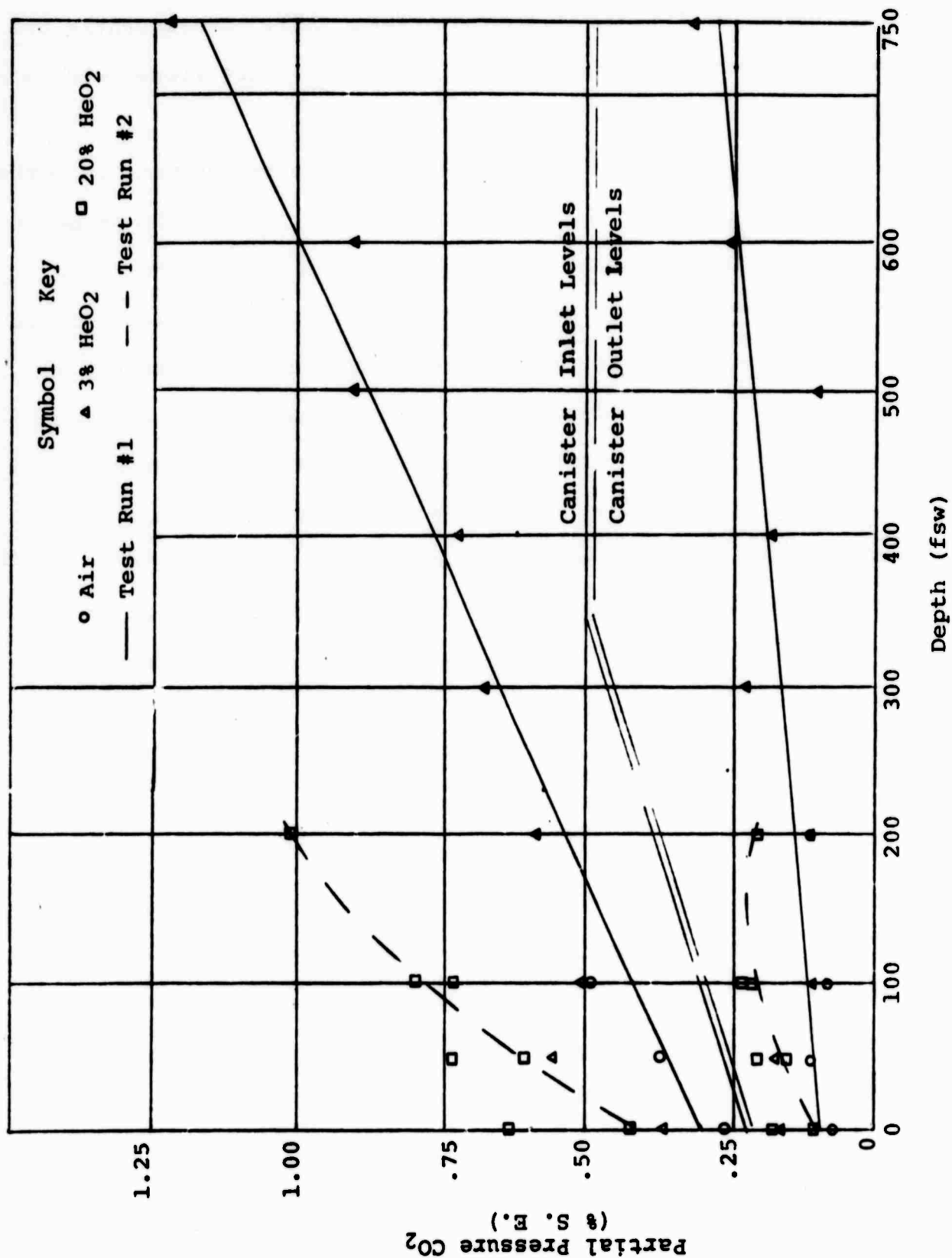
Figure 15   Canister Inlet and Outlet CO2 Levels
            Breathing Machine Ventilation Tests
            Advanced Mixed Gas Helmet

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accurate each time. The measured pressures nonetheless appear very low, particularly in light of much higher values obtained recently for a re-designed, but nonetheless basically similar, venturi in the Navy Prototype MK XII Helium-Oxygen Helmet (23). Consequently the indicated pressure rise figures for the venturi are viewed with some degree of reservation.

The recirculation rates occurring with the helmets in actual service may be slightly higher than those indicated. The presence of the dry gasometer in the recirculation loop retards the flow somewhat. The additional pressure drop imposed on the recirculation loop by the gasometer was not measured, and its actual effect on the system could not be determined. Dry gasometers are however supposed to be very low resistance instruments, and a check of the pressure rise generated by the venturi indicates that this was indeed the case. The pressure rise generated by the venturi, which must equal the total recirculation loop pressure drop, was in all cases indicated as 4 cm. H_2O or less subject to the reservation expressed above. Consequently, but subject to that same reservation, the flow retardation caused by the gasometer can be reasonably assumed to have been small, if any at all.

The position of the helmet exhaust valve had a considerable influence on the measured helmet pressures. This was discovered during the trial runs and repeated during the test runs. A representative pressure-time trace from the test runs is shown in Figure A-1, Appendix A. In that case opening the exhaust valve from the fully closed position to 1 turn open had no perceptible effect. However opening it 1/2 turn further to 1 1/2 turns open (approximately 1/2 way open) caused the peak exhalation and

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inhalation pressures to drop from +38 and +10 cm. H_2O respectively to 0 and -16 cm. H_2O respectively. The break point was later established during the test runs as being between 1 and 1 1/4 turns open.

The manufacturer at the time of these tests was recommending that the exhaust valve be set at 1 3/4 turns open. The manufacturer presently recommends that the exhaust valve be set at 1 1/2 to 2 1/2 turns open (26). For these tests the exhaust valve was set at 1 turn open. Previous experience had indicated that helmet pressures tended to become more negative with increasing depth (as indeed they did here) and that pressures as negative as those encountered at the surface with the exhaust valve set at 1 1/4 turns open would result in a flooded helmet well before the test could be completed.

With the exhaust valve set at 1 turn open, the maximum and minimum pressures developed in the helmet during respiration (relative to the test manikin's suprasternal notch 20 cm. below mouth center line) were quite large. The average peak exhalation pressures were about 40 cm. H_2O, the average peak inhalation pressures, about -20 cm. H_2O (see Figure 14 and Tables 3 and 4). Even with the high peak exhalation pressures, the peak inhalation pressures were still sufficiently negative to necessitate augmenting the seal between the helmet neck seal and the neck of the test manikin to prevent the helmet from flooding.

By the same token, however, the tape undoubtably contributed somewhat to the high measured inhalation and exhalation pressures by not allowing any neck seal leakage. Neckseal leakage on the human test subjects in the bicycle ergometer tests (Section V.C.1) and in

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the subjective test dives (Section V.C.2) was often quite large and was apparently of some importance in keeping down the measured peak pressures. This subject will be discussed in more detail in Section V.D.

The CO_2 levels found to exist in the helmet during these tests were always well below the 2.0% S.E. level considered to be the maximum safe level (25). The conditions tested are considered to represent moderate work; 30 lpm respiratory minute volume and 1.25 slpm oxygen consumption (20).

The solenoid on the No. 1 sample line (Figure 8) refused to seat at depths of 300 fsw and below. Consequently the inspired PCO_2 could not be measured at those depths (see the voids in Tables 3 and 4). Inspired PCO_2 could also not be measured on the surface at times due to insufficient differential pressure to drive the gas through the sample line to the measuring instrument.

At the depths where the inspired PCO_2 could be measured, it can be seen by inspection of Tables 3 and 4 that the canister inlet PCO_2 was very nearly equal to the inspired PCO_2. Consequently whenever the actual inspired PCO_2 was not available, it has been assumed herein that the canister inlet PCO_2, if available, was equal to it.

The error analysis (Appendix A, Tables A-1 and A-2) indicates that the CO_2 level reported in Tables 3 and 4 are reasonably accurate and valid. The measured differences between the test manikin's inspired and expired CO_2 levels differed from the expected 4.0% S.E. by a root-mean-square average of only .41% S.E. The indicated CO_2 elimination rate differed from the anticipated rate of 1.2 slpm by an rms average of only .17 slpm. The values in Tables 3 and 4 should all be considered accurate to $\pm$ .05% S.E. They were not

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rounded off to the nearest .1% because that only increased the
errors and made the error analysis more difficult.

The measured inhalation/exhalation pressures and all the
measured gas flows except those marked in Tables 3 and 4 are
considered to be reasonably accurate.

C. Manned Tests

1. Bicycle Ergometer Ventilation Tests

Tables 5, 6 and 7 present the complete data obtained from these tests.

A word is in order here regarding the relationship between the work loads placed on the test subjects in these tests and the diver work load simulated in the breathing machine ventilation tests reported in Section V. B.

The three work rates selected for use in the bicycle ergometer tests correspond nominally to oxygen consumption rates of 1.0, 1.5 and 2.0 slpm (18). The oxygen consumption rates which correspond to the actual CO_2 production rates listed in Tables 5, 6 and 7 can be estimated by making use of the respiratory quotient (RQ). The RQ is defined, as the ratio of CO_2 produced to O_2 consumed, and it varies from .85 to about .98 as a person increases from light to heavy work (27).

While on the saturation dive under consideration, the test subjects used both the Advanced Mixed Gas helmet and a Kirby Morgan KMB-8 Bandmask. The average CO_2 production rates and the corresponding estimated average O_2 consumption rates calculated by the respiratory quotient method are given in Table 8 for the 4 test subjects using both pieces of equipment.

As can be seen from Table 8 there was reasonably decent agreement between the expected oxygen consumption rates and the estimated average consumption rates based on the calculated CO_2 production rates and the respiratory quotient.

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Diver / Mode	Work Rate (Watts Mechanical)	Peak Inhalation Pressures (cm. H₂O) Avg.	Max.	Peak Exhalation Pressures (cm. H₂O) Avg.	Max.	Breathing Rate (Breaths per Minute)	Helmet Exhaust Flow Rate (acfm)	Canister Flow Rate (acfm)	CO₂ Readings (% S.E.) Helmet Exhaust	Canister Inlet	Canister Outlet	Indicated CO₂ Production Rate (slpm)	Concurrent KMB-8 Bandmask Test Data (17) Avg. CO₂ Production (slpm)	Breathing Rate (Avg.) (bpm)	Avg. Tidal Volume (liters)
Huckins Dry Suit Surface 30% HeO₂	51	No Pressure Variation				N.A.	A.N. Dry Suit Leaked	N.A.							
	81	Pressure Steady				N.A.		N.A.	No Reading Taken						
	113	at +7 cm. H₂O				N.A.		N.A.							
Davis Neck Seal Surface 30% HeO₂	51	-6	-13	+5	+6	19	>1.17	N.A.	No Readings Taken						
	81	-7	-11	+11	+13	16	>1.61	N.A.							
	113	-13	-17	+8	+13	19	>.91 / >1.2*	N.A.							
Huckins Neck Seal 200 fsw 16% HeO₂	51	-8	-13	+13	+20	11	.61	4.78	1.40	N.A. Instrument Failure	.06	N.A.	.87	12	1.8
	81	-11	-16	+9	+13	15	.59	→	1.61		.10	N.A.	1.43	15	2.1
	113	-17	-20	+18	+22	13	.77 / .64*	→	2.17		.18	N.A.	1.63	15	2.2
Waddell Neck Seal 200 fsw 16% HeO₂	51	-7	-14	+13	+15	23	.55	→	N.A. Instrument Failure	.83	.03	~1.20	1.37	11	2.6
	81	-11	-21	+14	+16	20	.53	→		.92	.10	~1.25	1.60	15	2.2
	113	-12	-18	+13	+16	25	.6 / .57	→	N.A.	N.A.	.10	N.A.	1.68	19	2.5

* 19 Minute Average

Table 5 Bicycle Ergometer Ventilation Test Results: Advanced He-O₂ Diving System, Surface Controls and 200 fsw. Date 9-11 March 1971

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Table 6. Bicycle Ergometer Ventilation Test Results:

Diver / Mode	Work Rate (Watts Mechanical)	Peak Inhalation Pressures (cm. H₂O) Avg.	Peak Inhalation Pressures (cm. H₂O) Max.	Peak Exhalation Pressures (cm. H₂O) Avg.	Peak Exhalation Pressures (cm. H₂O) Max.	Breathing Rate (Breaths per Minute)	Helmet Exhaust Flow Rate (acfm)	Canister Flow Rate (acfm)	CO_2 Readings (% S.E.) Helmet Exhaust	CO_2 Readings (% S.E.) Canister Inlet	CO_2 Readings (% S.E.) Canister Outlet	Indicated CO_2 Production Rate (slpm)	Concurrent KMB-8 Bandmask Test Data (17) Avg. CO_2 Production (slpm)	Concurrent KMB-8 Bandmask Test Data (17) Breathing Rate (Avg.) (bpm)	Concurrent KMB-8 Bandmask Test Data (17) Avg. Tidal Volume (liters)
Davis Neck Seal	51	-9	-13	+16	+19	14	.78	4.3	1.54	1.36	.32	1.61	.75	11	1.7
	81	-13	-20	+19	+21	15	.59		1.95	1.64	.36	1.89	1.10	11	1.8
	113	-24	-33	+19	+26	18	.67 / .51*		2.42	1.98	.68	2.03	2.00	14	2.2
Brewer Neck Seal	51	-8	-24	+16	+18	19	.45		1.40	1.02	.27	1.09	.91	13	1.6
	81	-10	-21	+17	+26	22	.64		1.77	1.50	.27	1.82	1.13	15	1.7
	113	-18	-66	+18	+22	31	.39 / .51*		2.25	1.84	.41	1.99	1.84	21	2.0
Waddell Neck Seal	51	-4	-3	+13	+14	15	>.36		1.50	.86	.32	.87	1.37	11	2.6
	81	-5	-6	+15	+17	21	>.34		1.50	.95	.32	.98	1.60	15	2.2
	113	-8	-12	+13	+1.5	21	>.34 / >.36*		1.78	1.29	.32	1.43	1.68	19	2.5

(Canister Flow Rate: 4.3 acfm held constant for all rows, indicated by arrow.)

* 18 Minute Average

Table 6 Bicycle Ergometer Ventilation Test Results:
Advanced He-O₂ Diving System used with a Neck Seal.
Depth: 300 fsw. Media: 16% HeO₂. Dates: 11-12 March 1971

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Table 7. Bicycle Ergometer Ventilation Test Results; Advanced He-O₂ Diving System used with a Modified Dunlop Dry Suit.

$$\text{Advanced He-O}_2 \text{ Diving System used with a Modified Dunlop Dry Suit.}$$

Diver / Mode	Work Rate (Watts Mechanical)	Peak Inhalation Pressures (cm. H₂O) Avg.	Peak Inhalation Pressures (cm. H₂O) Max.	Peak Exhalation Pressures (cm. H₂O) Avg.	Peak Exhalation Pressures (cm. H₂O) Max.	Breathing Rate (Breaths per Minute)	Helmet Exhaust Flow Rate (acfm)	Canister Flow Rate (acfm)	CO₂ Readings (% S.E.) Helmet Exhaust	CO₂ Readings (% S.E.) Canister Inlet	CO₂ Readings (% S.E.) Canister Outlet	Indicated CO₂ Production Rate (slpm)	Concurrent KMB-8 Bandmask Test Data (17) Avg. CO₂ Production (slpm)	Concurrent KMB-8 Bandmask Test Data (17) Breathing Rate (Avg.) (bpm)	Concurrent KMB-8 Bandmask Test Data (17) Avg. Tidal Volume (liters)
Davis Dry Suit	51	No Pressure Variation					>.35		1.32	1.00	.31	1.03	.75	11	1.7
	81	Pressure Steady					>.29	4.3	1.40	1.14	.31	1.21	1.10	11	1.8
	113	at +8 cm. H₂O					≥40 >.36*		1.78	1.51	.31	1.72	2.00	14	2.2
Huckins Dry Suit	51	No Pressure Variation					N.A., Dry suit Leaked		1.50	.95	.32	.95	.87	12	1.8
	81	Pressure Steady							1.40	1.30	.36	1.35	1.43	15	2.1
	113	at +8 cm. H₂O							1.28	1.70	.36	1.82	1.63	15	2.2

*18 Minute Average

Depth: 300 fsw. Media: 16% HeO₂. Dates: 11-12 March 1971

Work Rate (watts, nominal)	60	90	120
Expected O_2 Consumption (slpm)(18)	1.0	1.5	2.0
Avg. CO_2 Production by the test divers when using the Advanced Mixed Gas helmet (slpm)	1.13	1.42	1.80
Corresponding Estimated Average O_2 Consumption (slpm)(27)	1.25	1.54	1.90
Avg. CO_2 Production by Divers When Using a KMB-8 Bandmask under identical conditions of depth, work rate and supply gas mixture (17)	.98	1.32	1.78
Corresponding Estimated Average O_2 Consumption (slpm)(27)	1.09	1.42	1.88

Table 8

Estimated Average Oxygen Consumption Rates

Figure 16 shows the accepted relationship between tidal volume and oxygen consumption. From it, it can be seen that the oxygen consumption appropriate to the 30 lpm tidal volume used in the breathing machine tests is approximately 1.25 slpm. Consequently the work rate corresponding to the breathing machine tests is roughly mid-way between the 2 lower work rates used in the bicycle ergometer tests.

(The oxygen consumption of the divers when they were using the KMB-8 Bandmask may also be estimated by using Figure 16 since their tidal volumes were known in that case. This procedure however gives quite different estimated oxygen consumption rates: 87, 1.07, and 1.58 slpm respectively at the 3 work rates. The respiratory quotient method is considered by the author to be the more accurate of the 2 methods in this case, and it was the method chosen.)

The helmet gas consumption and back pack recirculation rates are not influenced by diver work rate (assuming, of course, that the control valve is left closed). The gas consumption and recirculation rate values obtained in these tests were very similar to those obtained in The Breathing Machine Ventilation Tests, and they are plotted on Figure 13 for comparison with the values obtained in those tests.

The peak inhalation and exhalation pressures measured in these tests when the divers were wearing neckseals were generally, but not always considerably lower than those measured in the Breathing Machine Ventilation Tests. Figure 17 shows the average peak pressures obtained in these tests superimposed on Figure 14, Peak Inhalation and Exhalation Pressures, Breathing Machine Tests.
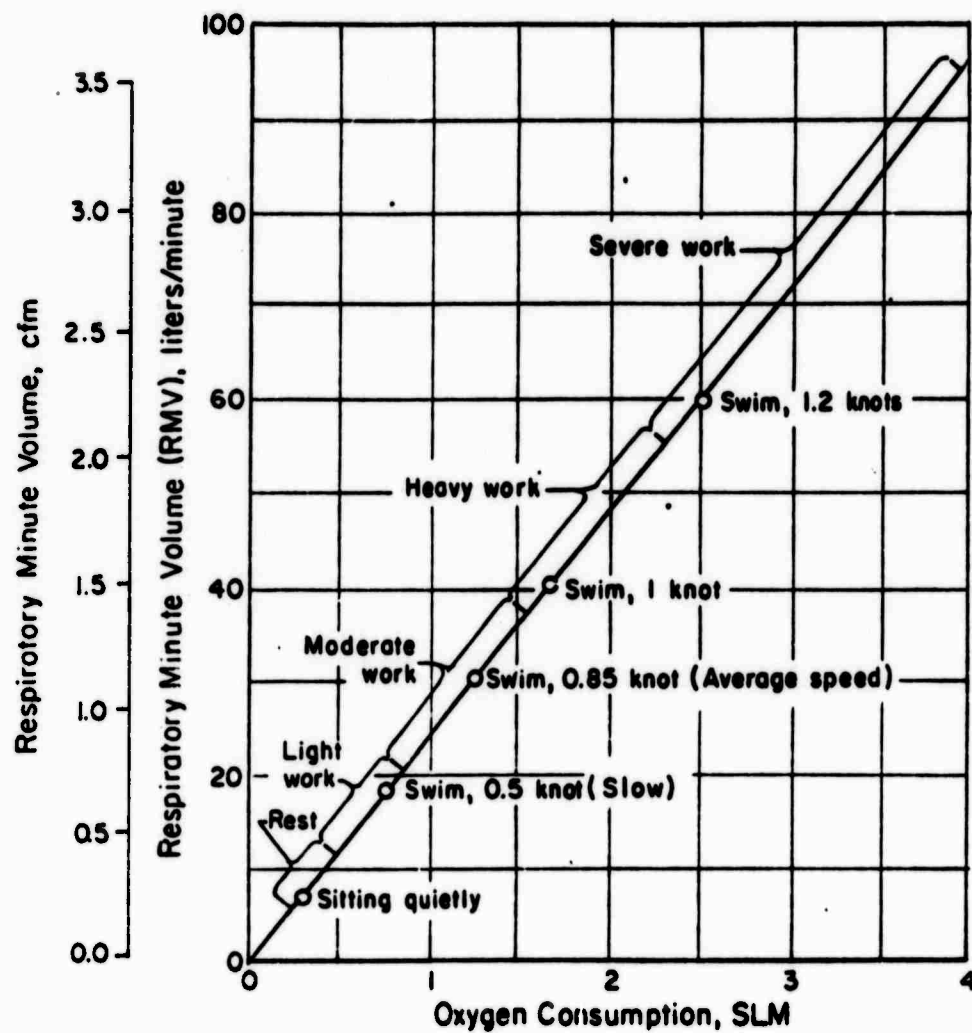
57

FIGURE 16. Relation of Respiratory Volume and Oxygen Consumption
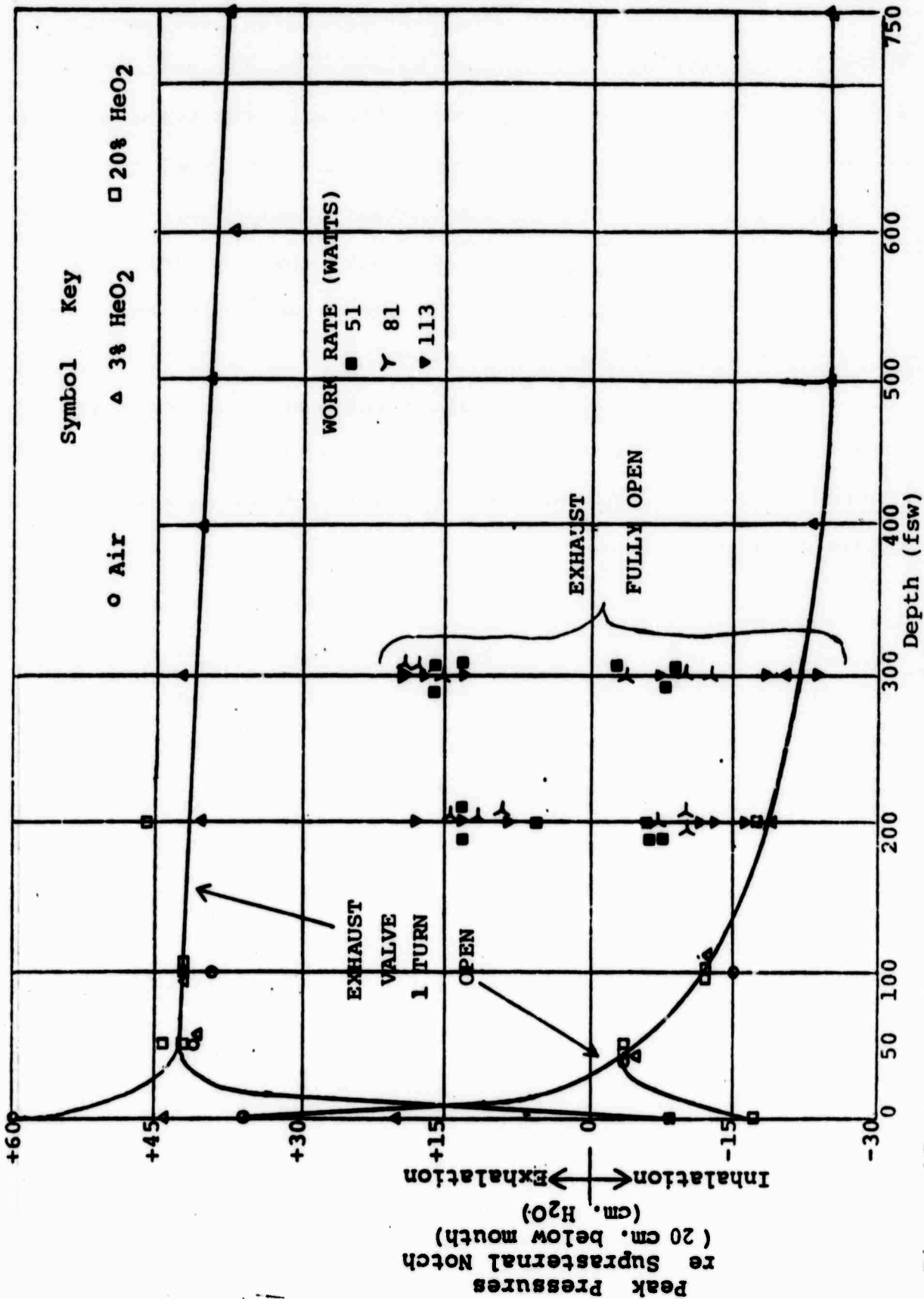to Type and Level of Exertion (20)

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Figure 17 Average Peak Inhalation and Exhalation Pressures Obtained in the Bicycle Ergometer Tests Superimposed on the Peak Inhalation and Exhalation Pressures Obtained in the Breathing Machine Ventilation Tests.

When the divers wore dry suits there were no detectable respiration-induced pressure variations in the helmets (see Tables 5 and 7). This is of course expectable since the diver's chest is inside the boundaries of the breathing apparatus, and the total volume of the breathing apparatus, helmet plus dry suit, is not affected by the diver's respiration. Whenever dry suits were used; the helmet pressure generally assumed a constant level of +7 to +8 cm. H_2O relative to outside chamber atmosphere. The diver's were allowed to adjust the helmet exhaust valve to their own preference. When wearing dry suits, they always adjusted it to the fully opened position.

There are 2 major items which account for most, if not all, of the wide differences between the peak helmet pressures measured in the Breathing Machine tests and those measured in the Bicycle Ergometer Tests.

First the divers, who were given their freedom to do so, always adjusted the helmet exhaust valve to the fully open position. Figure B-1 of Appendix B shows that subject Waddell (the first subject to use the helmet with a neckseal at 200 or 300 fsw) generated peak exhalation and inhalation pressures of +35 and -4 cm. H_2O respectively when he had the helmet exhaust valve fully closed. When he adjusted the exhaust valve to the fully open position, the exhalation and inhalation pressures fell to +12 and -8 cm. H_2O respectively. This is very similar to Figure A-1 of Appendix A. There, at the surface during the Breathing Machine Ventilation Tests, opening the exhaust valve from 1 to 1½ turns open had the effect of reducing the peak exhalation and inhalation pressures from +38 and +10 cm. H_2O respectively to 0 and -16 cm. H_2O respectively.

The position of the exhaust valve on the Advanced Mixed Gas helmet clearly has a pronounced effect on the pressure variations induced in the helmet by the diver's respiration. This effect is significant enough to account for nearly all of the differences in the peak pressures measured during the two testing sequences (see Figure 17).

The second item which accounts for some of the difference is the fact that on the test subjects the neckseal almost always leaked, whereas on the test manikin it was taped and not allowed to leak. Figure B-2, Appendix B illustrates some of the effects of neckseal leakage. When subject Brewer had the neckseal turned with the cuff up, thereby tending to allow leakage into, but not out of, the helmet, his peak inhalation pressures were only about -24 cm. H_2O. However when he turned the neckseal cuff down so that it tended to allow leakage out of, but not into, the helmet, his peak inhalation pressures jumped to -50 cm. H_2O and higher. All the while his peak exhalation pressure remained constant at +16 cm. H_2O.

This phenomenon, plus the effect of the helmet exhaust valve discussed earlier suggest very strongly that the apparent glaring discrepancy in the helmet pressure data between the Breathing Machine and the Bicycle Ergometer Ventilation Tests (Figure 17) is not a discrepancy at all, but rather simply the effect of helmet exhaust valve position plus an indeterminant amount of neckseal leakage.

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This neckseal leakage had another effect. Particularly in the cases where the neckseal cuff was turned up, enough chamber atmosphere leaked into the helmet system to make the measured oxygen levels meaningless. Consequently the measured oxygen levels for the neckseal runs were all thrown out.

This problem was not present with the dry suits. They invariably leaked where they were taped to the diver's torso. However, there the leakage was always outward since a constant 7-8 cm H_2O positive pressure was maintained in the suit at all times when a test run was in progress. Even in this case however the diver oxygen consumption rates indicated by the helmet flow rate and the difference between the oxygen percentages in the helmet and in the supply gas were unrealistically high (almost always 3 slpm or more), consequently the helmet oxygen levels from these runs were discarded also.

Neither of the above problems was considered to invalidate the measured CO_2 levels. Leakage of chamber atmosphere into and/or out of the helmets undoubtedly affected the accuracy of the measured CO_2 levels to some extent. However since the chamber CO_2 level was never far from the helmet CO_2 level (0.5 vs. 1.0-2.0% S.E.) and because the rate of chamber gas leakage into or out of the helmet could not even approach the 4-5 cfm recirculating through the canister this effect was almost certainly negligible.

Figure 18 contains a plot of the measured canister inlet PCO_2 levels against estimated oxygen consumption. Canister inlet PCO_2, though not equal to inhaled PCO_2, can be safely assumed to be close to it. As can be seen from Figure 18, the canister inlet PCO_2 stayed under the recommended maximum limit of 2.0% S.E. (28) during all of the tests conducted. The test results from the
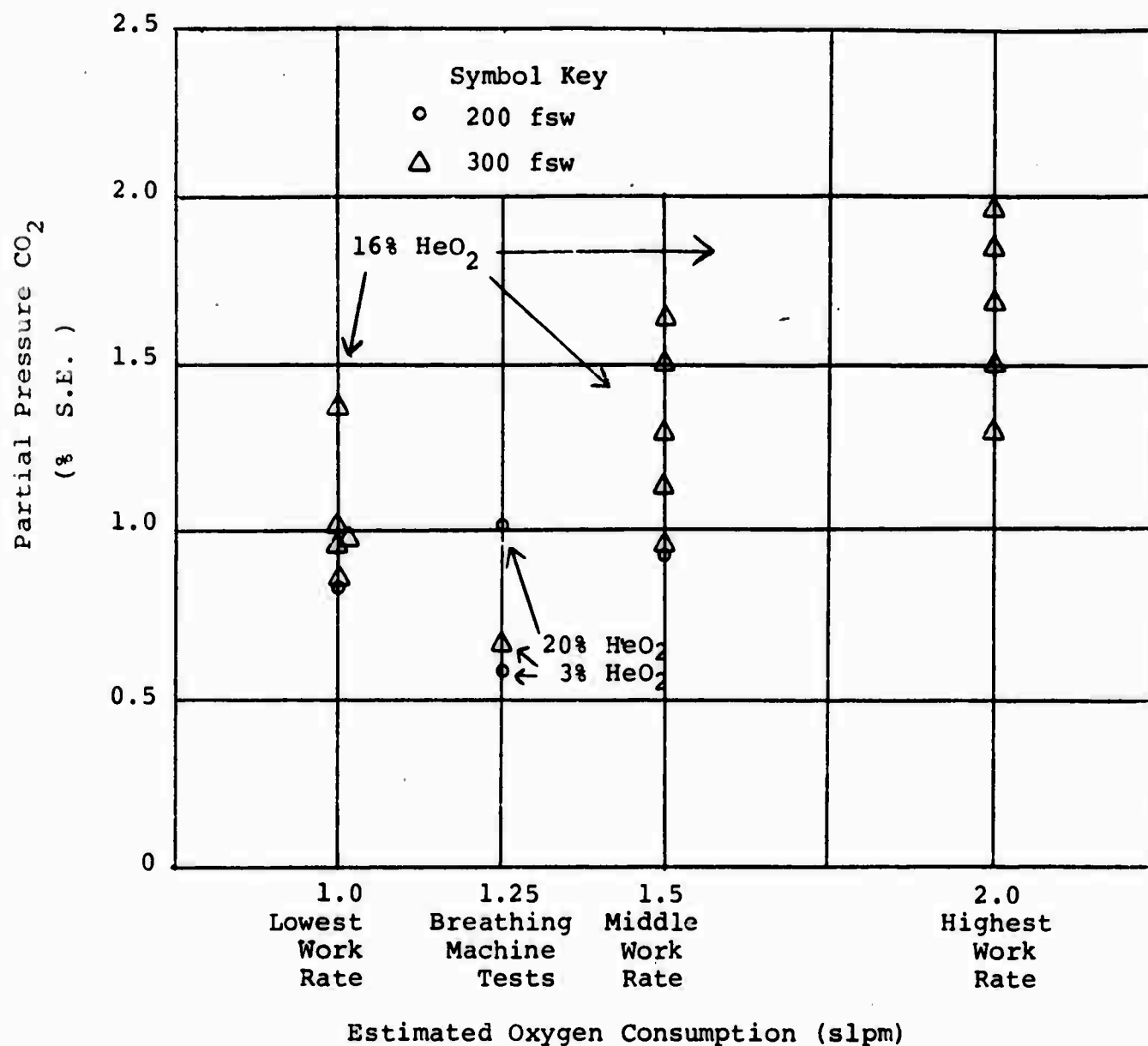
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Figure 18

CO_2 Levels, Bicycle Ergometer Ventilation Tests
and Breathing Machine Ventilation Tests at
200 and 300 fsw.

Breathing Machine Tests on 20% HeO_2 agree closely with the results reported in this Section for test divers using 16% HeO_2.

The 3% HeO_2 results from the Breathing Machine Tests are somewhat lower as might be expected. The total flow through the helmet (gas consumption plus recirculation rate - Figure 13) was approximately 20% higher when 3% HeO_2 was used than it was when either 16 or 20% HeO_2 were used.

It should be re-iterated here that the above-mentioned CO_2 levels were all for reasonably fresh baralyme charges in the cannister. They do not in any way indicate what type of cannister life may be expected.

There were very few subject complaints of discomfort during these tests, even from Brewer who drew the huge inhalation peak pressures (Figure B-2). At no time were any of the subjects unable to complete the work sequences.

It is worth noting here that the subject's average breathing rates, were higher for the same work rates and supply gas (16% HeO_2) when using the Advanced Helmet and neckseal system than they were when using the Kirby-Morgan Bandmask. Breathing rates for the subjects when they were using the Advanced Helmet and Modified Dunlop Dry Suit combination were unfortunately not available. Table 9 below presents the average breathing rates as a function of breathing apparatus and work rate.

Work Rate (Watts)	Average Breathing Rate (breaths per minute)	
	Advanced Mixed Gas Helmet and Neckseal	Kirby-Morgan KMB-8 Bandmask
51	16.8	11.8
81	18.2	14.0
113	21.2	17.3

Table 9

Average Breathing Rates for the 4 Test Subjects as a Function of Work Rate and Breathing Apparatus Used.

The significance of the breathing rate differences expressed in Table 9 is uncertain. However, they support the suggestion that in a neckseal type helmet the divers tend to breath shallower and faster in an effort to keep down the peak pressures occurring in the helmet.

2. Subjective Test Dives

Good gas analysis data was obtained from 19 of the 20 dives conducted. Table 10 lists the results.

Below 60 fsw the drops in the measured oxygen percentages were always less than the 2% normally allowed for in venturi-type helmets (28). No detailed effort was made to calculate accurate diver oxygen uptakes since the accuracy of the Beckman F-3 analyser used was reliably only ±0.5%. However a quick check of the helmet oxygen loss (supply % O_2 - helmet % O_2) times the appropriate helmet gas consumption rates from Figure 13 yields indicated diver oxygen uptakes of .6 and 1.4 slpm respectively at 230 and 300 fsw, the only two depths for which helmet gas consumption data is available from Figure 13. These don't appear very accurate when compared to the expected average oxygen uptake of about 1.0 slpm, and they aren't. However, they do indicate that the measured oxygen levels are reasonable.

The CO_2 levels measured in the cannister output were almost always very low. Helmet CO_2 levels themselves were not measured. However from the indicated oxygen uptakes and the very low canister output CO_2 levels it may be reasonably inferred that they were less than 2.0% S.E.

The diver's comments regarding the helmet were mixed. Most liked its maneuverability, its light weight and its ease of donning and doffing. However diver complaints of one type or another were almost universal. The detailed diver comments are contained in Appendix C. Other evaluation forms were also used, but the questions

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Diver	Depth/Time (fsw)/(minutes)	Oxygen Level (%)		CO$_2$ Level (% S.E.) Outlet	
		Supply Gas	Helmet	Average	Maximum
Hesket	60/30	40	36.3	0.00	0.00
Holton	60/30	40	37.0	0.03	0.05
Petrasek	60/40	40	36.9	0.07	0.09
Eubanks	60/45	40	37.0	0.07	0.10
Roan	60/45	40	37.0	0.02	0.35
Reimers	60/45	40	36.4	0.06	0.11
Milner	60/50	40	37.0	0.01	0.02
Eubanks	60/50	40	36.7	0.32	0.46
Clinton	60/50	40	36.0	0.06	0.11
Roan	60/60	42	38.4	0.09	0.16
Roan	60/120	-	-	0.03	0.06
Eubanks	150/20	-	-	0.02	0.02
Clinton	150/30	28	27.5	0.04	0.04
Ault	150/30	28	26.7	0.00	0.02
Clinton	230/20	20	19.5	0.00	0.00
Larimore	230/20	20	19.5	0.00	0.00
Templin	230/20	20	19.5	0.00	0.00
Larimore	300/15	16	15.2	0.00	0.00
Wiobe	300/15	16	14.8	0.00	0.00

Table 10

Oxygen and Canister Outlet CO$_2$ Levels,
Subjective Test Dives, Advanced Mixed
Gas Helmet, October-November 1970

on the "Swimming Test Operations" questionaires reproduced in Appendix C evoked the most descriptive responses. The most common diver complaints are discussed below.

Almost to a man the divers complained of jock strap discomfort. The jocking arrangement for the Advanced helmet consists of a single adjustable strap through the diver's crotch attached to the helmet by 2 cables front and back (See Figures 1, 2, 4 and 5). Unless the helmet is jocked very securely it tends to move about on the diver's shoulders. This can be very annoying. In particular the rapid bendover-stand up - bend over routine of the weight lifting task often resulted in the diver's head repeatedly striking the front and rear of his helmet.

The complaints of jock strap discomfort were also related to the respiration-induced pressure variations in the helmet. If the helmet exhaust valve was closed, the pressure in the helmet on exhalation became quite positive (as reported in Section V. B). This caused the helmet to tend to rise up off the diver's shoulders on exhalation and to settle back down again on inhalation, in effect to "bob". When this happened, the helmet also became difficult to keep in place. If the helmet were jocked tight enough to prevent bobbing, then the jock strap became uncomfortable.

On the other hand, if the helmet exhaust valve were opened (past about 1½ turns) the annoying bobbing stopped, but it became almost impossible to keep the helmet from taking on water past the neckseal. If in this situation, the diver wanted a reasonably large inhalation, there simply was not enough displaceable volume in

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the helmet from which to get it. As a result the diver inhaled until he met resistance, then exhaled and inhaled until he met resistance again, etc. Each time the diver inhaled until he met resistance, he would generate sufficient negative pressure in the helmet relative to outside water pressure to draw a small amount of water past the neckseal. (Refer again to Figure B-2).

Consequently most of the divers had to make a choice between having a bobbing helmet or having a cupful or so of water in the neckseal as a frequent companion. Many chose the cupful of water. In that situation however the proximity of the helmet canister suction port to the helmet exhaust valve opening was a constant source of concern. A wrong move when purging the helmet of water or a careless one at almost any moment could easily dump any water in the helmet directly into the canister suction hose.

The other complaint that was frequently heard was a result, primarily of the helmet's buoyancy, but also somewhat of its jocking system. As most of the diver's used it, the helmet tended to be slightly negative. Consequently when they were swimming against the trapeze ergometer, the helmet would slide forward and rest on the backs of their heads. This quickly resulted in tired necks.

Again most of the divers liked the Advanced Mixed Gas system and considered it in several ways an improvement over the Navy's MKV Helium-Oxygen Helmet. However, the items mentioned above usually made it a bit uncomfortable, and the tendency of the neckseal to leak was disconcerting.

D.   General Comments.

What maximum inhalation and exhalation pressures are
desirable, or even tolerable, in a helmet are not known at this
time. With open circuit SCUBA regulators where the peak pressure
and the average pressure are very nearly equal, peak pressures of
over 20 cm H_2O are nearly intolerable, and even lower peak pressures
are required for regulators approved for U.S. Navy use (24).

In neckseal type helmets a typical pressure-time plot
closely resembles a saw tooth. Consequently the time-average
inhalation or exhalation pressures are often only half of their
respective peaks. Also the phase relationship between respiratory
flow and helmet pressure remains unknown at this time. Consequently,
it is not possible at this time to say what constitute reasonable
inhalation and exhalation pressures and what do not.

The -40 cm H_2O and -20 cm H_2O peak exhalation and
inhalation pressures produced by the breathing machine (Section
V.B.) at breathing rates corresponding to moderate work with the
helmet exhaust valve set at 1 turn open are quite large especially
considering the 1.0 liter tidal volume used. The Bicycle Ergometer
test subjects (Section V. C.1) always set their exhause valves at
full open so they didn't generate such large pressures in their
helmets. Brewer's periodic -60 cm H_2O inhalation pressures were the
one exception to this. The subjective test subjects (Section V. C. 2)
tried a variety of exhaust valve settings. In their case a fully
closed exhaust valve resulted in excessive peak pressures as in
Section V.B and attendent helmet bob. A fully opened exhaust
valve, however, encouraged neckseal leakage.

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The experiences with the Advanced Mixed Gas Helmet recapped above all speak of inadequate variable volume in the helmet. All tests except the highest work rate on the bicycle ergometer were representative of light to moderate work.

The Advanced Mixed Gas Helmet when used with a neckseal is considered suitable for moderate, but not for heavy work due to respiratory pressure considerations.

When the helmet is used with a constant **volume suit**, the pressure fluctuations mentioned above do not occur. When used in that mode, the helmet's performance limitations are simply its ability to scrub CO_2 and supply O_2.

With the gas mixtures normally used in HeO_2 diving supplying sufficient oxygen to the diver is rarely a problem. The tests reported herein indicate that the Advanced Mixed Gas Helmet will maintain safe CO_2 (less than 2.0% S.E.) levels at work rates up to and including heavy work (O_2 consumption = 2.0 slpm) at all depths down to 300 fsw provided that:

1. Gas mixtures appropriate to the depth are used.
2. The CO_2 absorbant canister is operating effectively.
3. The supply pressure is 100 psi overbottom pressure or more.
4. All components are in good working order.

Subject to the same provisions expressed above, the data contained herein indicates that at moderate work rates (Figure 15) it may be possible to safely use the helmet as deep as 750 fsw. Further testing, particularly with human test subjects, should however be accomplished before such use is attempted.

VI. CONCLUSIONS

The conclusions given below are strictly valid only for the particular system tested. The system tested consisted of an Advanced Mixed Gas Diving Helmet, Model 3000, Serial Number 412 used with an Advanced Model 3700 Back Pack Scrubber and Standard Advanced Neckseals. All components were in factory condition at the time they were tested. The applicability of the conclusions expressed below to other helmets of the same type is dependent on the quality control exercised by the manufacturer. At this time there is no reason to suspect that other helmets of the same type will not possess essentially similar characteristics since they are manufactured by modern small assembly line techniques. However, if there is doubt regarding a specific helmet it should be tested.

Unless stated otherwise the conclusions expressed below also apply to the Advanced Mixed Gas Helmet and Back Pack Scrubber when used with a neckring and constant volume suit.

A. The sound levels existing in the helmet were into damage risk levels under many of the conditions tested. The conditions tested are considered representative of most normal air diving situations.

B. With proper precautions the helmet may be used without risking damage to the diver's hearing.

C. When the system is used on 16% or 20% HeO_2, the total flow rate through the helmet (gas consumption plus re-circulation rate) exceeds 4.5 cfm down to and including 300 fsw providing that the supply pressure is maintained at 100 psi overbottom pressure.

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D. When the helmet is used with a neckseal, the pressure variations in the helmet caused by respiration rates appropriate to moderate work are sufficient to cause some diver discomfort. With the exhaust valve closed the positive pressures generated during exhalation tend to lift the helmet from the diver's shoulders. With it fully open negative pressures generated during inhalation are sufficient to frequently cause neckseal leakage.

E. When the helmet is used with a neckring and a constant volume suit, there is no restriction on the maximum diver ventilation (breathing) rates due to helmet pressure considerations.

F. The CO_2 levels existing in the helmet at diver work rates appropriate to heavy work (2.0 slpm oxygen consumption respiratory minute volumes of up to 50 lpm) will be within recognized safe limits (less than 2.0% S.E.) in the depth range 0 to 300 fsw provided that:

   1. Gas mixtures appropriate to the depth of the dive are used.

   2. The CO_2 absorbant canister is operating effectively.

   3. The supply pressure is maintained at not less than 100 psi overbottom pressure.

   4. All components are in good working order.

G. The agent primarily responsible for the wide pressure variations found in the helmet-neckseal combination is insufficient variable volume in the helmet-neckseal combination.

H. There is some evidence which suggests that the helmet may be safely used well beyond 300 fsw, perhaps as deep as 750 fsw.

VII. Recommendations

A. No significant USN use of this helmet is presently contemplated. However, prior to any significant USN use, more thoroughly instrumented sound level testing should be conducted to augment the data contained herein.

B. If the helmet is to be used prior to the completion of A above, it is recommended that the daily exposure times in the helmet be controlled such that noise exposure limits based on the data contained herein are not exceeded. Basically, this means limiting a diver's time in the helmet in most instances to not more than 4 hours per 24 hour period.

C. For future work it is recommended that instrumentation improvements be implemented and/or instruments be obtained to permit the monitoring and measurement of of helmet flow rates and pressures during manned test dives.

D. It is recommended that efforts be initiated to develop meaningful guidelines for acceptable helmet pressure variations resulting from the diver's respiration. These guidelines would most likely be in the form of maximum external work of respiration rather than in the form of pressure limitations.

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Appendix A.

1. Error Analysis, Breathing Machine Ventilation
   Tests, Tables A-1 and A-2.

2. Effect of Helmet Exhaust Valve Position
   on the Measured Helmet Pressures,
   Figure A-1.

3. Samples of Recorder Outputs from Breathing
   Machine Ventilation
   Tests No. 1 and 2, Figures A-2 and A-3.

Depth (fsw)	0	50	100	100	200	300	400	500	600	750	50	0
Respiratory Rate (Breaths per minute)	15	→										
Tidal Volume (Liters per breath)	2.0	→										
Gas Composition	Air	→	3% HeO$_2$ →									
CO$_2$ Addition Rate (slpm)	1.2	→										
				↑CONTROLLED VARIABLES↑				↓MEASURED VARIABLES↓				
CO$_2$ Eliminate Rate (slpm)*	1.21	-	1.23	1.07	.97	.82	.85	1.16	.83	1.07	1.22	1.21
Difference: CO Add -CO$_2$ Eliminate	-.01	-	-.03	+.13	+.23	+.38	+.35	+.04	+.37	+.13	-.02	-.01
Expired-Inspired PCO$_2$ (% S.E.)**	4.65	4.23	4.26	4.0	3.97	3.76	3.71	3.55	4.06	4.69	3.91	>4.63
Expected Exp.-Insp. PCO$_2$ Diff. (% S.E.)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Variation: Diff. Expected-Actual	-.65	-.23	-.26	.00	+.03	+.24	+.29	+.45	-.06	-.69	+.09	<-.63

* Calculated as follows:
 [Canister Inlet PCO$_2$-Canister Outlet PCO$_2$]x [Recirculation Rate]
 plus [Canister Inlet PCO$_2$ x Gas Consumption] = [CO$_2$ Elimination Rate]
 Canister Inlet PCO$_2$ is assumed equal to helmet exhaust PCO$_2$.
 Helmet Gas consumption is assumed equal to helmet exhaust rate.

** Calculated as follows:
 [Expired PCO$_2$-Inspired PCO$_2$] = [Exp.-Insp. PCO$_2$].
 When Inspired PCO$_2$ values were not available, Canister Inlet PCO$_2$ values were assumed
 approximately equal.

Table A-1 Error Analysis, Breathing Machine Ventilation Tests, Advanced He-O$_2$ Diving Helmet, Test No. -, 23 February 1971

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Depth (fsw)	0	50	100	200	100	50			RMS Average Tables A-1&A-2
Respiratory Rate (Breaths per minute)	15	→							
Tidal Volume (Liters per breath)	2.0	→							
Gas Composition	20% HeO₂	→							
CO₂ Addition Rate (slpm)	1.2	→							
CO₂ Eliminate Rate (slpm)*	1.23	1.17	1.20	1.38	1.07	1.21			
Difference: CO Add -CO₂ Eliminate	-.03	+.03	.00	-.18	+.13	-.01			.17
Expired-Inspired PCO₂ (% S.E.)**	4.68	4.40	4.40	4.78	3.85	4.17			
Expected Exp.-Insp. PCO₂ Diff. (% S.E.)	4.00	4.00	4.00	4.00	4.00	4.00			
Variation: Diff. Expected-Actual	-.68	-.40	-.40	-.78	+.15	+.17			.41

← CONTROLLED VARIABLES → ← MEASURED VARIABLES →

* Calculated as follows:

[Canister Inlet PCO_2 - Canister Outlet PCO_2) × Recirculation Rate]
plus [Canister Inlet PCO_2 × Gas Consumption] = [CO_2 Elimination Rate]
Canister Inlet PCO_2 is assumed equal to helmet exhaust PCO_2.
Helmet Gas consumption is assumed equal to helmet exhaust rate.

** Calculated as follows:

[Expired PCO_2 - Inspired PCO_2] = [Exp.-Insp. PCO_2]
When Inspired PCO_2 values were not available, Canister Inlet PCO_2 values were assumed
approximately equal.

Table A-2   Error Analysis, Breathing Machine Ventilation Tests, Advanced He-O_2 Diving Helmet,
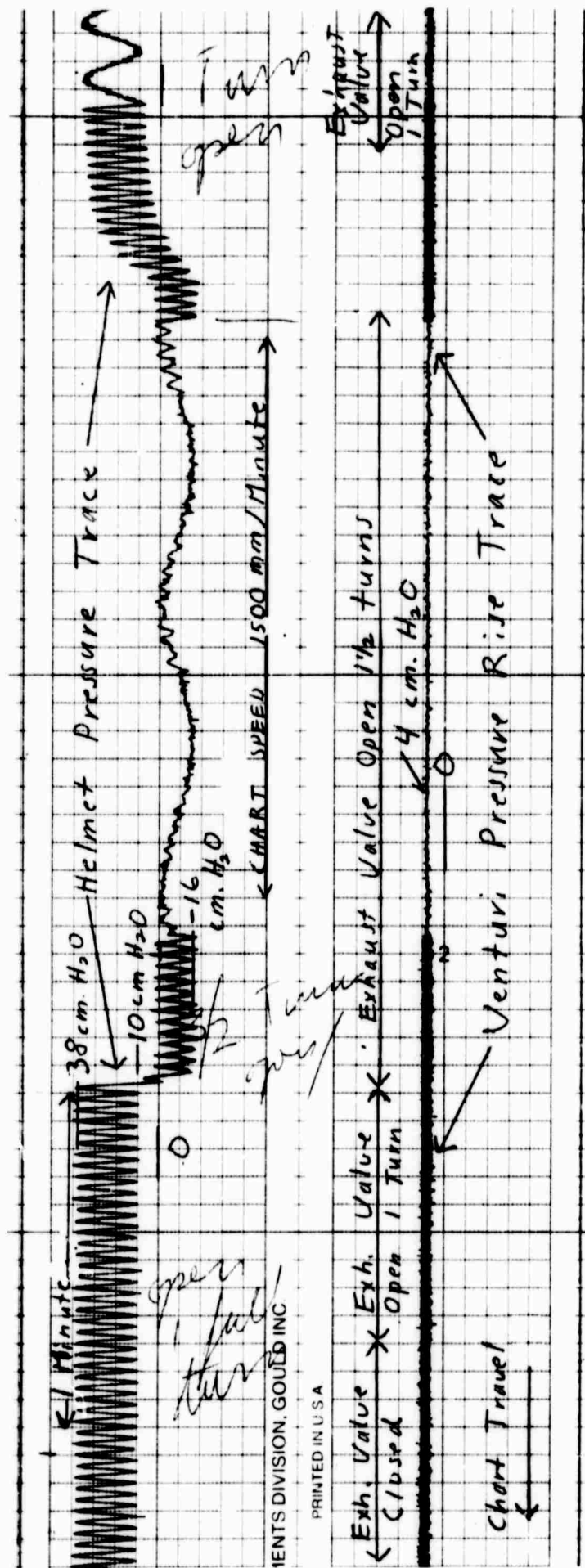Test No. 2, 23 February 1971.

Figure A-1 Effect of Helmet Exhaust Valve Position on the Measured Helmet Pressures

83
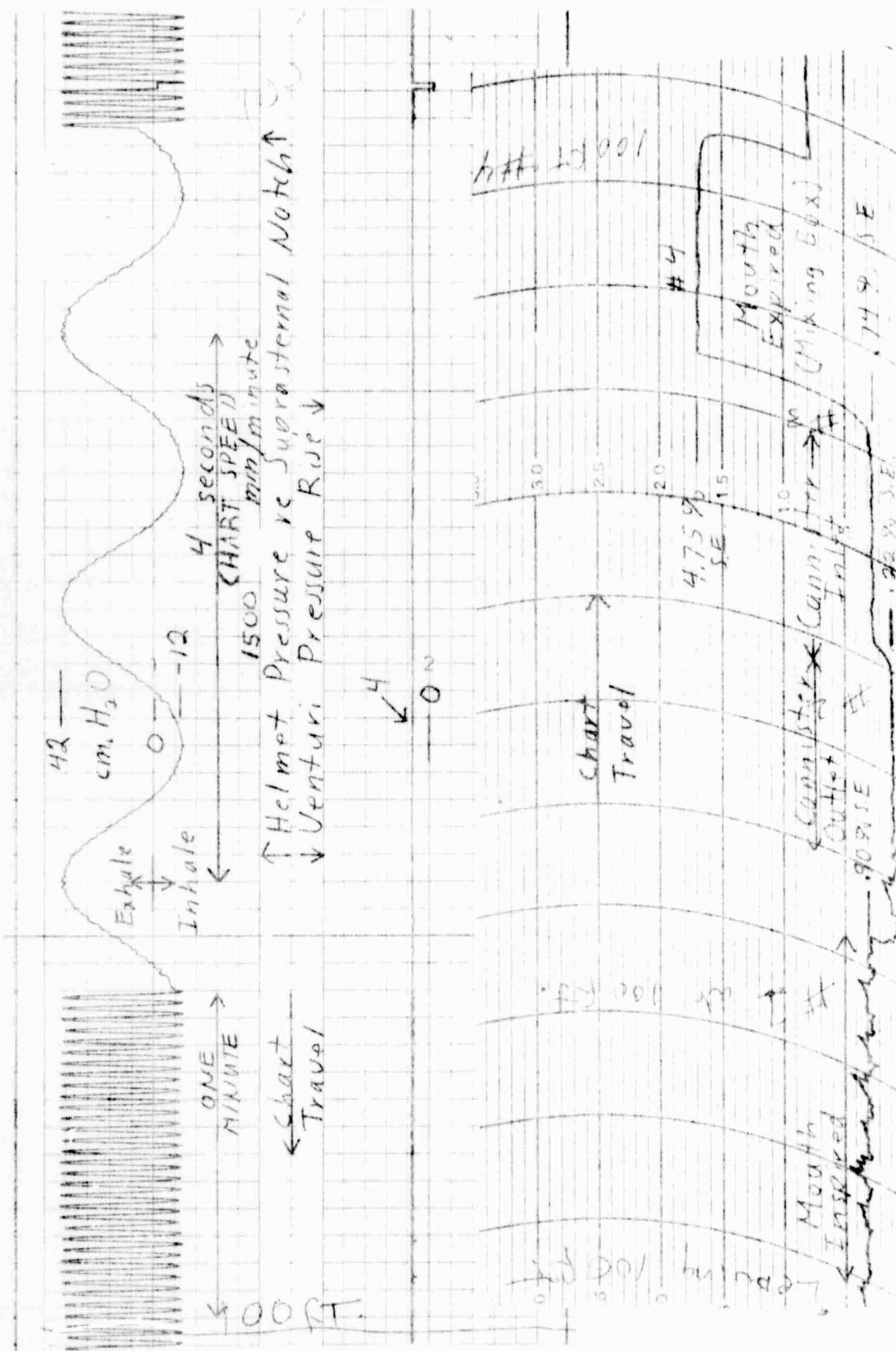
Figure A-2   Pressure Transducer and CO₂ Analyzer
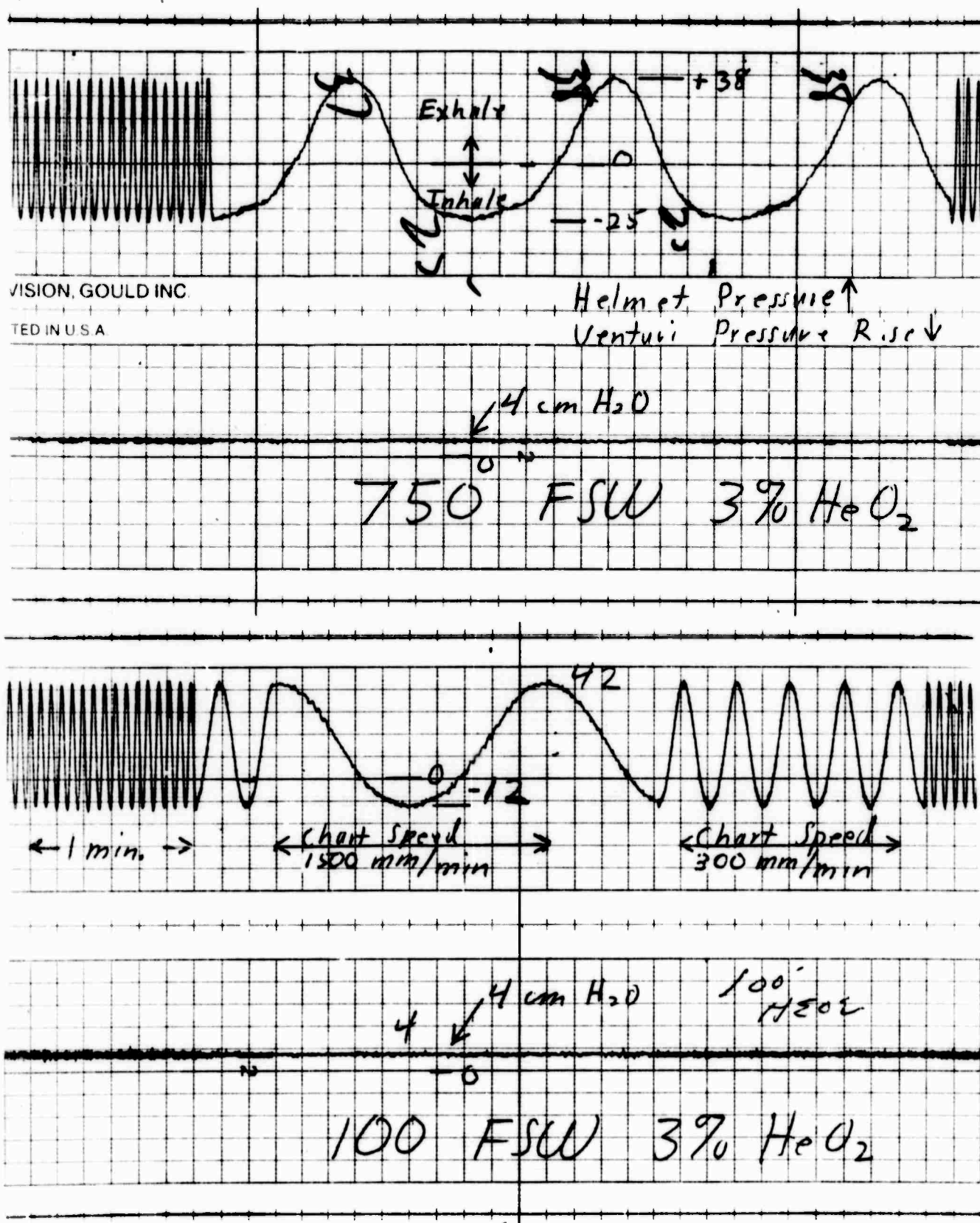   Recorder Traces, Test #2, 100 fsw on
             Ascent

Figure A-3   Pressure Transducer
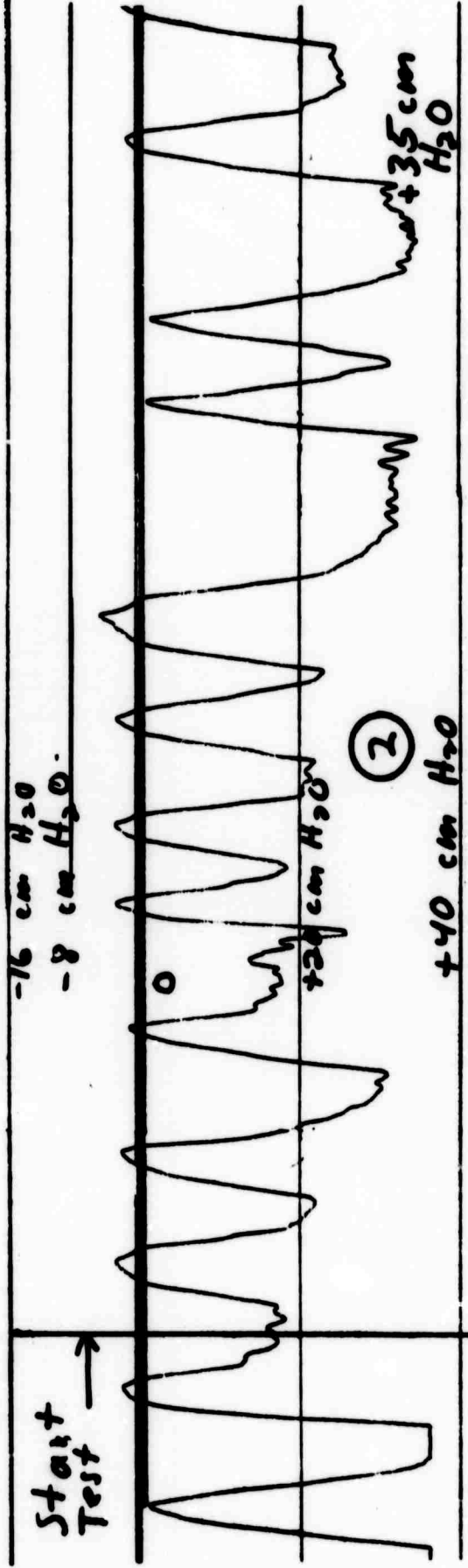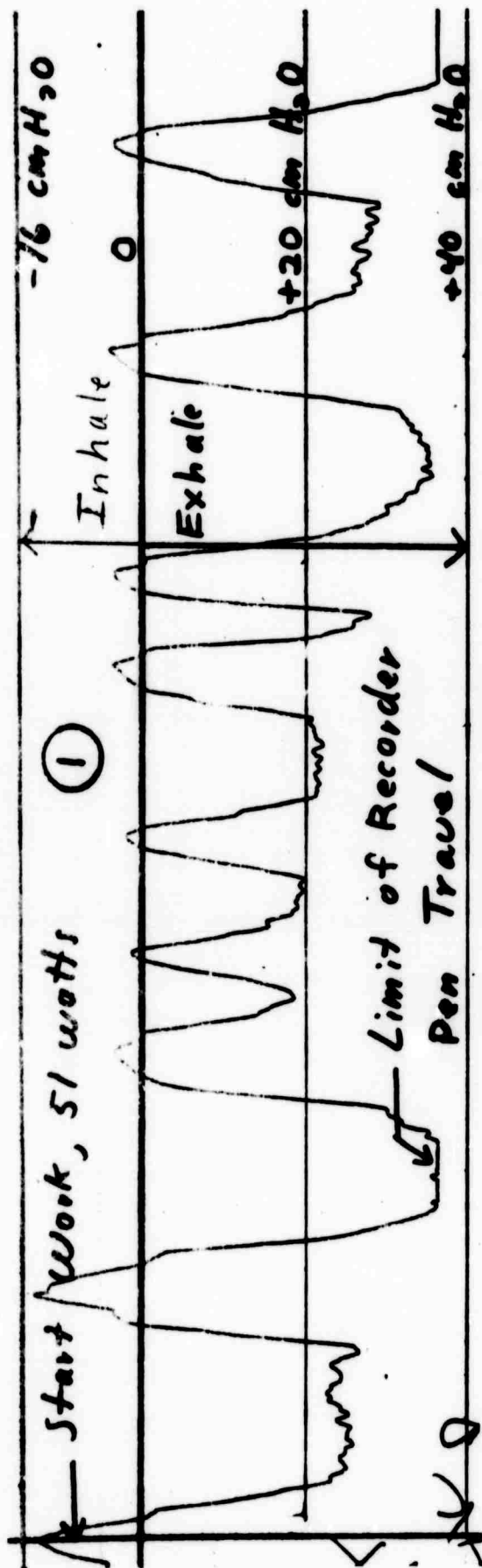   Recorder Traces,
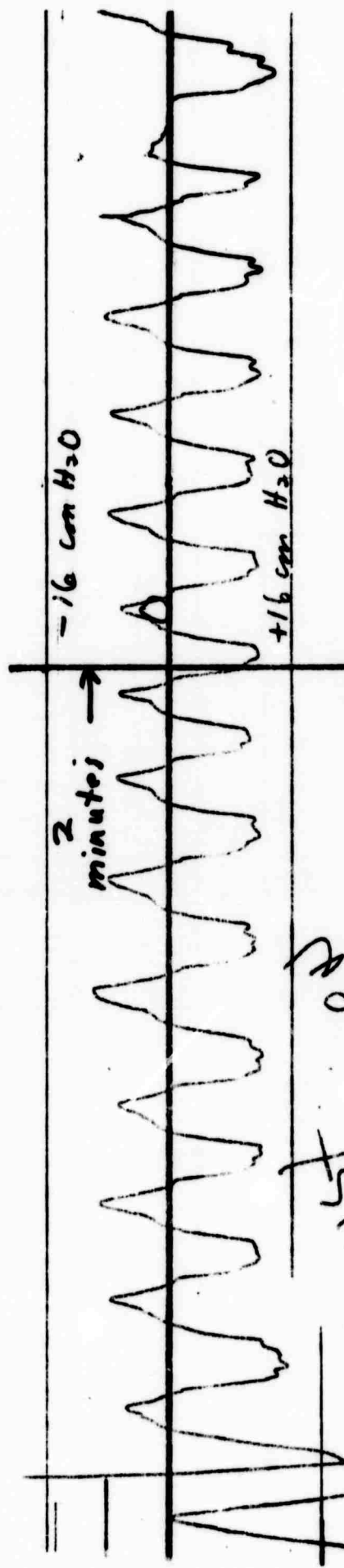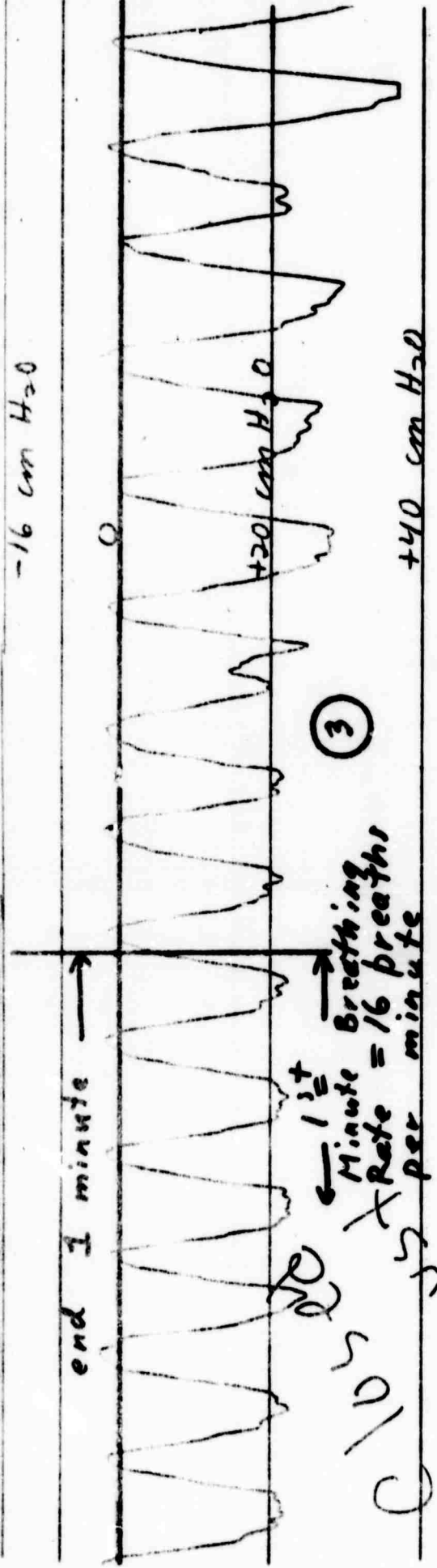   Test #1, Descent

APPENDIX B

Helmet Pressure vs. Time for Subject

Waddell at 200 fsw Using a Neckseal

Figure contains the entire first 6-minute work period and the first 45 seconds of the last minute of the third work period. Chart speed is 0.5 cm./sec. unless otherwise indicated. Vertical sensitivity is 8 cm. H_2O pressure/cm.

Note the effect of the helmet exhaust valve. During strips 1-3 the exhaust valve is fully closed and the helmet pressures are highly positive. At the beginning of strip 4 (approx. $1\frac{1}{2}$ minutes into the work period) the exhaust valve is opened and the helmet pressure decreases markedly. The peak exhalation pressures drop from approx. 35 cm. H_2O to approx. 12 cm. H_2O; the peak inhalation pressures from approx. -4 to approx. -8 H_2O.

Note also the increase in the subject's breathing rate from 16 (1st minute) to 25 (6th minute) as he adjusts to the helmet and his work rate.

Figure B-1, Page 2

-16 cm H_2O

$+40$ cm H_2O

$+40$ cm H_2O

end 1 minute

1st Minute Breathing Rate = 16 breaths per minute

③

-16 cm H_2O

$+16$ cm H_2O

2 minutes

④

→ Helmet Exhaust →

Valve Remains at Full Open Pressure Thereafter

Opening Exhaust Valve Note Drop in Helmet Pressure

$+40$ cm H_2O

Fig B-1, Page 3

90

Fig. B-1, Page 4

91

-16 cm H₂O 5 min. 0 +16 cm H₂O

⑧

← Last minute breathing rate = 23 bpm →

6 min ↑ Inhale -16 cm H₂O 0 +16 cm H₂O Exhale

⑨

End First Six Minute Work Period

← -20 cm H₂O ↑ Inhale 0 Exhale +20 cm H₂O →

⑩

← 13th Minute Breathing Rate = 25 bpm.

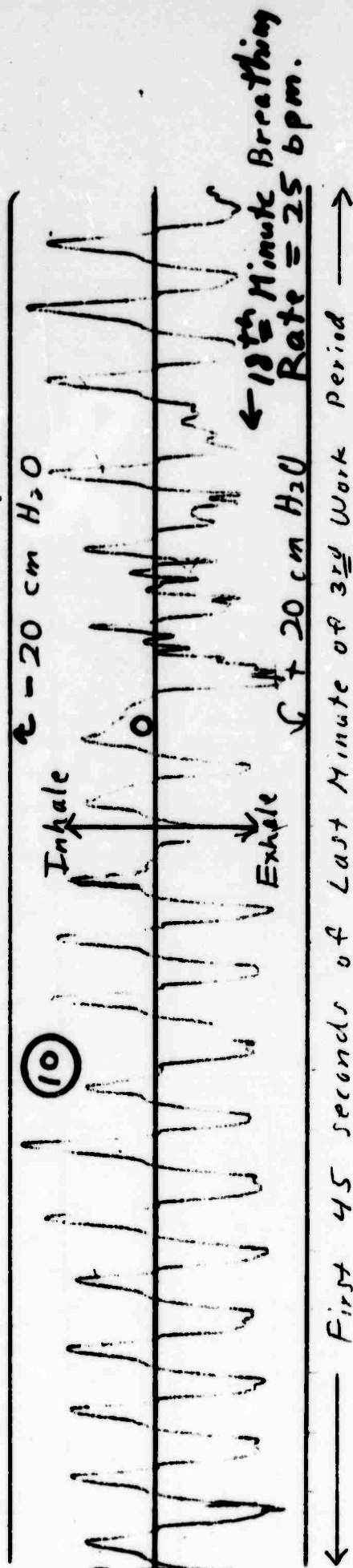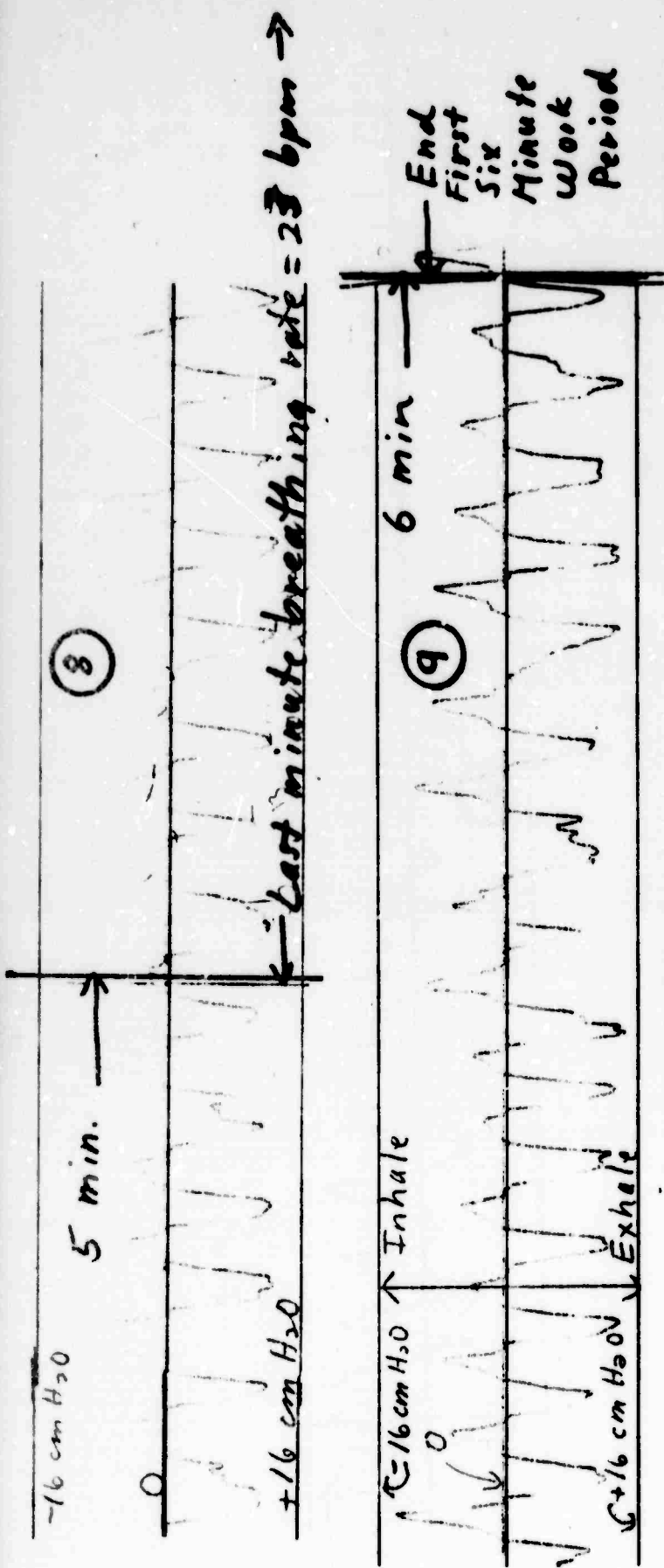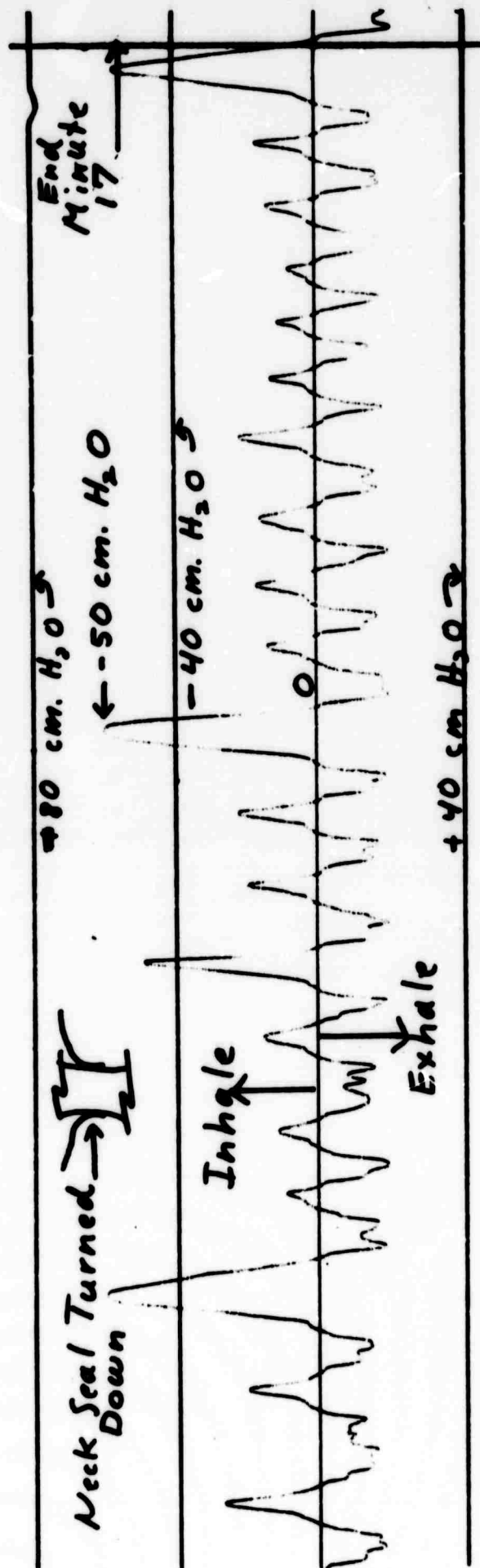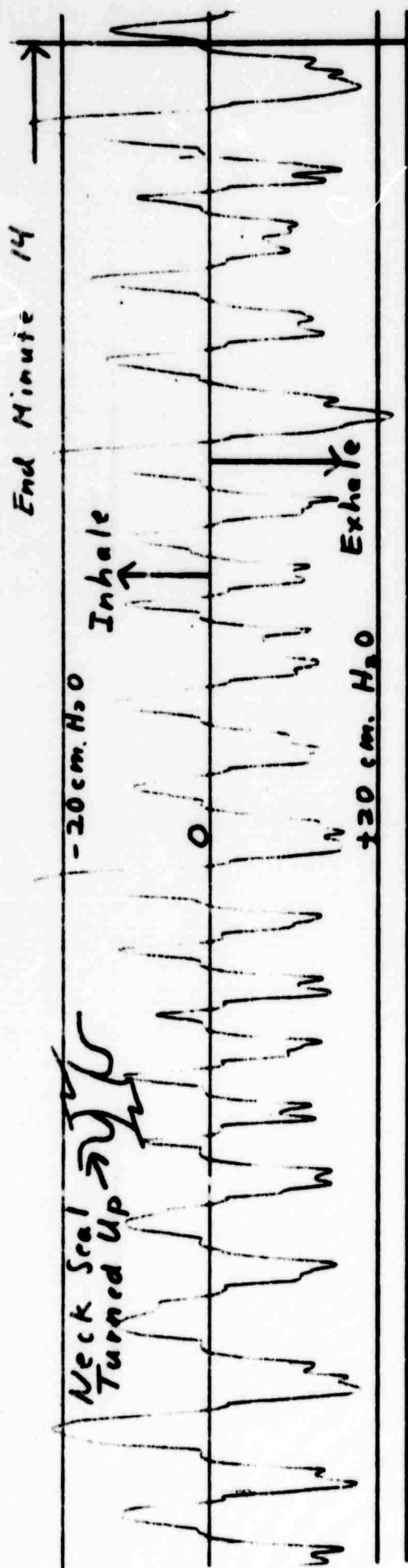← First 45 seconds of Last Minute of 3rd Work Period →
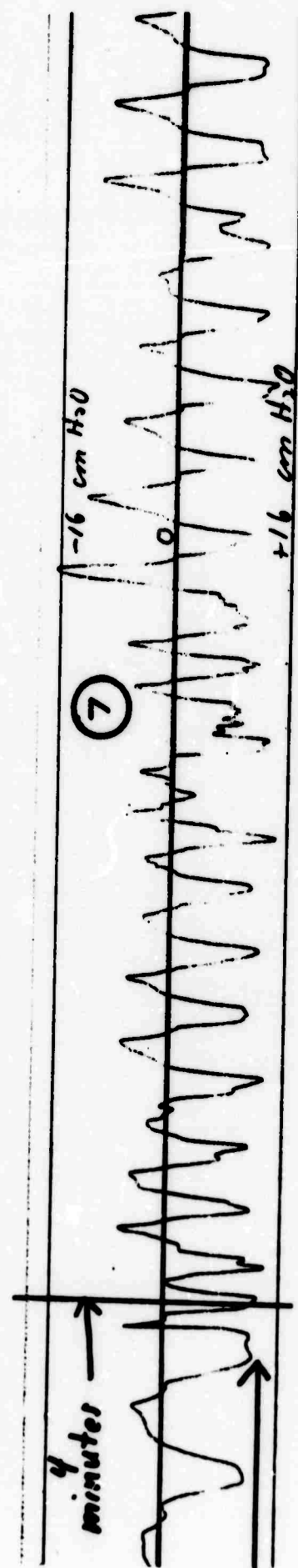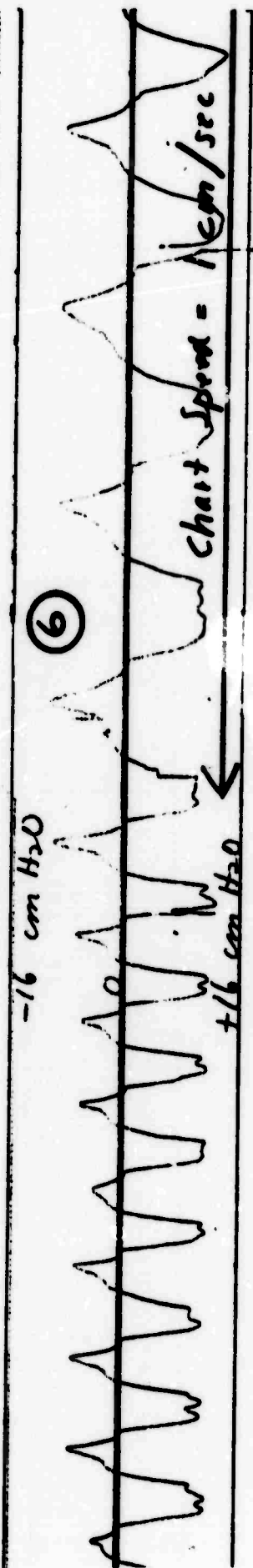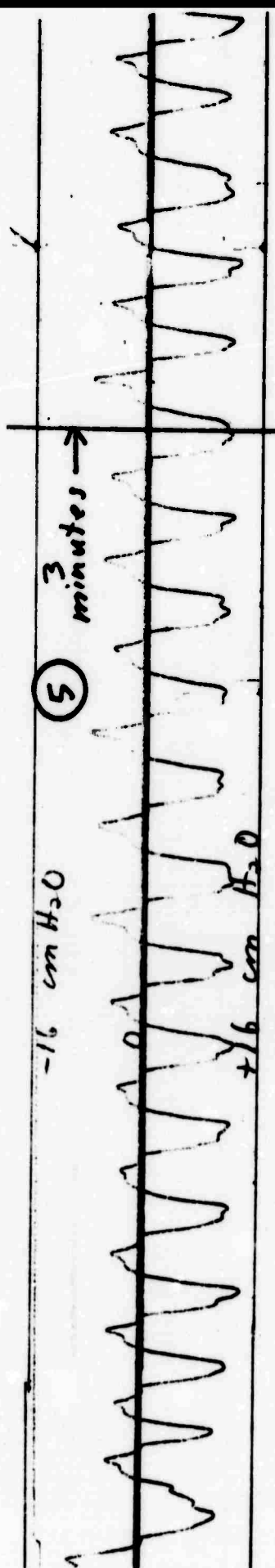
Fig B-1, Page 5

Figure B-2

Effect of Having Neckseal Turned Up or Down. Subject is Brewer at 300 fsw during 3rd Work period. Chart speed is 0.5 cm./second. Note the periodic demand for a large inhalation.

Appendix C

"Swimming Test Observations"

Post-Dive Questionaires

completed by the subjective

test divers, Oct.-Nov. 1970

SWIMMING TEST OBSERVATIONS

Apparatus: __Advanced HeO$_2$__   Project: __Swim and Lift Weights__

1. **Describe the general comfort of the apparatus.**
    If the hat did not fall forward, the comfort would be excellent.

2. **Describe the general fit of the harness.**
    The addition of a waist strap to the jock would improve the fit.

3. **Describe the general swimmability of the equipment.**
    Swimming is easy, but the hat laying on the back of one's head causes
    discomfort. When the hat takes on water while swimming, the water tends to
    run into the exhaust to the canister

4. **Describe the specific buoyancy characteristics.**
    When the exhaust valve is closed, the helmet has a tendency to be quite
    buoyant.

5. **Describe the specific torque characteristics.**
    None

Observer: __Ault, BM1 (DV)__   Date: __28 October 1970__

Dives: 150/30
         60/20
         60/30

SWIMMING TEST OBSERVATIONS

Apparatus: Advanced HeO$_2$ **Project:** Swim and Lift Weights

1. **Describe the general comfort of the apparatus.** Fairly comfortable. More comfortable than USN He-O$_2$ rig. However, with a loose jock the helmet floats up and instantly hits the chin; with a tight jock the genitals are sacrificed.

2. **Describe the general fit of the harness.** See #1. Recommend a different type of jock, possibly a pant or parachute type. Also recommend replace snaphooks they constantly place pressure on sterum and between shoulders.

3. **Describe the general swimmability of the equipment.**
   Easy to swim, but floods easily when in a horizontal position. Often tends to flood in any position except upright.

4. **Describe the specific buoyancy characteristics.**
   On inhalation helmet comes down to rest on your shoulders. On exhalation with a tight jack a strain is placed on the genitals. With a loose jock the front edge of the helmet hits the chin.

5. **Describe the specific torque characteristics.**

Observer: Clinton, HM1 (DV)   **Date:** 26 October-2 November 1970

Dives: 60/40
       140/10
       230/20

98

SWIMMING TEST OBSERVATIONS

Apparatus: __Advanced HeO$_2$__   Project: __Swim and Lift Weights__

1. Describe the general comfort of the apparatus.

    Fair except that helmet slips and jock is uncomfortable.

2. Describe the general fit of the harness.

    Cannister or harness slips. The snap hooks on the back sometimes ride under the cannister and cause discomfort. The tension on the jock strap is really uncomfortable.

3. Describe the general swimmability of the equipment.

    When recirculating, it floods easily. When bending over or doing a lot of maneuvering, you keep losing the neckseal.

4. Describe the specific buoyancy characteristics.

    The hat slips around a lot and is hard to keep in a comfortable position.

5. Describe the specific torque characteristics.

    The only way to keep the helmet from slipping around when you are lifting weights is to wedge   your chin in the neck band. Otherwise the up and down movement of lifting weights will cause the helmet to hit you in the back of the head.

Observer: __Roan DCC (DV)__   Date: __27 October 1970__

         Dives: 60/45
                          60/60
                          60/120

SWIMMING TEST OBSERVATIONS

Apparatus: _____Advanced HeO$_2$_____   Project:_Swim and Lift Weights_

1. Describe the general comfort of the apparatus.

    The apparatus is awkward to swim in a horizontal position. The helmet falls forward and hits you in the back of the head. The helmet shifts around a lot and no matter what size neckseal you have, you flood out a lot when swimming.

2. Describe the general fit of the harness.

    The harness is very poor. If you tighten the harness as tight as is necessary, you feel like you're cutting yourself in two.

3. Describe the general swimmability of the equipment.

    Poor.

4. Describe the specific buoyancy characteristics.

    Helmet tends to be negative.

5. Describe the specific torque characteristics.

    Poor.

Observer: _Larimore SF1_____   Date: _2, 3 & 4 Nov, 1970_____

       Dives: 60/40
                  230/20 (2)
                  300/15

SWIMMING TEST OBSERVATIONS

Apparatus: ___Advanced HeO$_2$___   **Project:** Swim and Lift Weights

1. **Describe the general comfort of the apparatus.**
   Not too bad weight wise. The neckring tends to cut into your shoulders
   when you lift your arms over your head. The hat is sloppy on your head
   when you move to one side or the other. If the jock were changed a little,
   it wouldn't be bad.

2. **Describe the general fit of the harness.**

   Good

3. **Describe the general swimmability of the equipment.**

   Good

4. **Describe the specific buoyancy characteristics.**

   Not bad

5. **Describe the specific torque characteristics.**

   Okay, if the helmet would ride more snugly on your shoulders.

Observer: ___Wiebe, BM1 (DV)___   **Date:** ___3 November, 1970___

   Dives: 300/15

SWIMMING TEST OBSERVATIONS

Apparatus: __Advanced HeO$_2$__   Project: __Swim and Lift Weights__

1. Describe the general comfort of the apparatus.

    Jocking device is very uncomfortable. Helmet hits back of head
    when lifting weights.

2. Describe the general fit of the harness.

    Fits well.

3. Describe the general swimmability of the equipment.

    Hat comfort is fair while swimming, but the hat rests on the back
    of your head and after a few minutes your neck begins to ache.

4. Describe the specific buoyancy characteristics.

    Helmet is very buoyant, and this is very noticeable during heavy
    breathing. It bobs up and down no matter how it is jocked down.

5. Describe the specific torque characteristics.

    Side torque is okay. However helmet would rock back and forth and
    cause some discomfort.   .

Observer: __Templin A01 (DV)__   Date: __2 Nov. 1970__

          Dives: 230/20

SWIMMING TEST OBSERVATIONS

Apparatus: <u>Advanced HeO$_2$</u> Project: <u>Swim and Lift Weights</u>

1. Describe the general comfort of the apparatus.
   a. Helmet is a little too positive.
   b. Noise level is too high.
   c. Neckseal was not effective
   d. Jock strap causes great discomfort.

2. Describe the general fit of the harness.
   Good

3. Describe the general swimmability of the equipment.
   Helmet does not swim well because of its weight.

4. Describe the specific buoyancy characteristics.
   Too positive.

5. Describe the specific torque characteristics.
   Noticeable, but not excessive.

Observer: <u>Milner (civilian)</u> Date: <u>27 Oct. 1970</u>

   Dives: 60/40

SWIMMING TEST OBSERVATIONS

Apparatus: __Advanced HeO₂__   Project: __Swim - Lift Weights__

1. **Describe the general comfort of the apparatus.**
   Quite good if exhaust valve set at 1 3/4 turns open as recommended by manu-
   facturer. Poor if exhaust fully closed. Generally, comfort good if used
   with a dry suit, only fair if used with a neckseal.

2. **Describe the general fit of the harness.**
   Backpack harness is very easy to work.

3. **Describe the general swimmability of the equipment.**
   Fair. Any water in the helmet runs into the faceplate and blurs vision.

4. **Describe the specific buoyancy characteristics.**
   See below *

5. **Describe the specific torque characteristics.**

Observer: __Reimers, ENS__   Date: __23 October 1970__

          Dives: 60/50

* Not enough variable volume in the helmet at 1 3/4 turns open on
exhaust valve (i.e., comfortable setting). Each time the diver takes
a deep inhalation (i.e., any work rate except rest) all he does is draw
water in past the neckseal. If he closes the exhaust valve so he
doesn't get water leakage past the neckseal, the helmet bobs up and
down on his head and shoulders and the jock starts to cut in.

SWIMMING TEST OBSERVATIONS

Apparatus: <u>Advanced He-O$_2$</u>   **Project:** <u>Swim and Lift Weights</u>

1. **Describe the general comfort of the apparatus.**   Very bad. Snap hooks on neckring fore and aft dig into skin. Jock strap painful. Neckring digs into shoulders on ·the surface. Rig always shifting forward.

2. **Describe the general fit of the harness.**
   Okay except for above. Should modify jock straps possibly to a parachute harness type.

3. **Describe the general swimmability of the equipment.**
   Rig is not suited for swimming. Neckring too large. Must stop continuously to clear rig of water.

4. **Describe the specific buoyancy characteristics.**
   Varies with each breath. Semi-closed circuit delivers too much gas or exhaust valve needs to be continuously used.

5. **Describe the specific torque characteristics.**
   Poor. Helmet wobbles around. Only thing that holds the helmet and neckring is the jock strap. Water continuously leaking in when in <u>any</u> position except vertical (standing up). Jock strap chafs when lift<u>ing</u> weights.

Observer: <u>Hesket, NM1 (DV)</u>   **Date:** <u>16 & 26 October 1970.</u>

          Dives 60/30
                60/20

SWIMMING TEST OBSERVATIONS

Apparatus: __Advanced He-O$_2$__ Project: __Swim & Lift Weights__

1. **Describe the general comfort of the apparatus.**
   Good except for the jock.

2. **Describe the general fit of the harness.**
   Good

3. **Describe the general swimmability of the equipment.**
   N/A

4. **Describe the specific buoyancy characteristics.**
   Good

5. **Describe the specific torque characteristics.**
   Good

Observer: __Petrasek, BMC (DV)__ Date: __14 October 1970__

  Dives: 60/40

SWIMMING TEST OBSERVATIONS

Apparatus: <u>Advanced HeO$_2$</u>   **Project:** <u>Swim and Lift Weights</u>

1. **Describe the general comfort of the apparatus.**
   Jock strap was very uncomfortable in the water. Hat sits on top of head out of water.

2. **Describe the general fit of the harness.**
   Fair

3. **Describe the general swimmability of the equipment.**
   Hat has a tendency to slide back and forth and floods easily.

4. **Describe the specific buoyancy characteristics.**
   Fair

5. **Describe the specific torque characteristics.**
   Didn't notice any difficulties.

Observer: <u>Holton MR1 (DV)</u>   **Date:** <u>27 October 1970</u>

Dives: 60/34